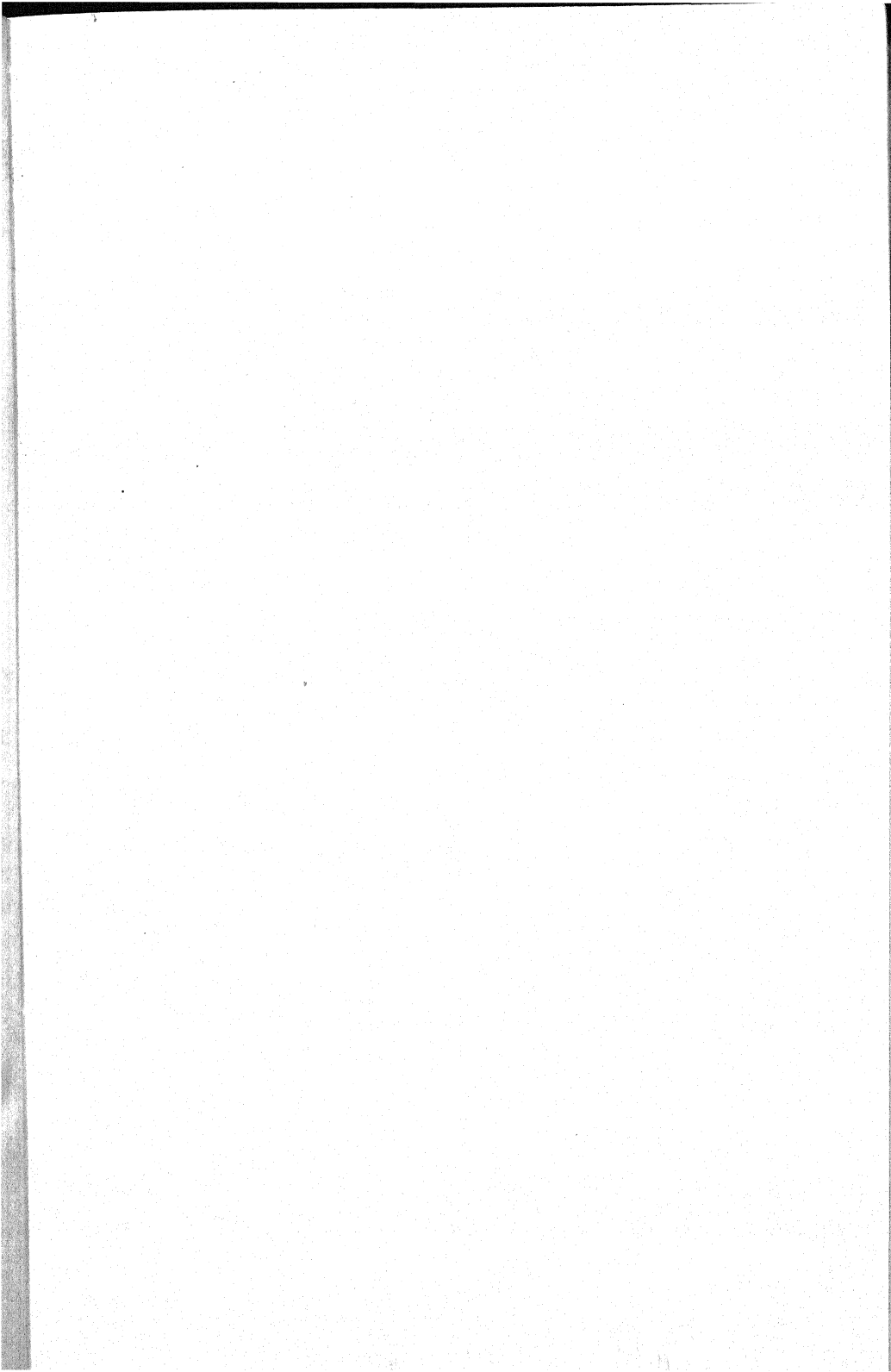
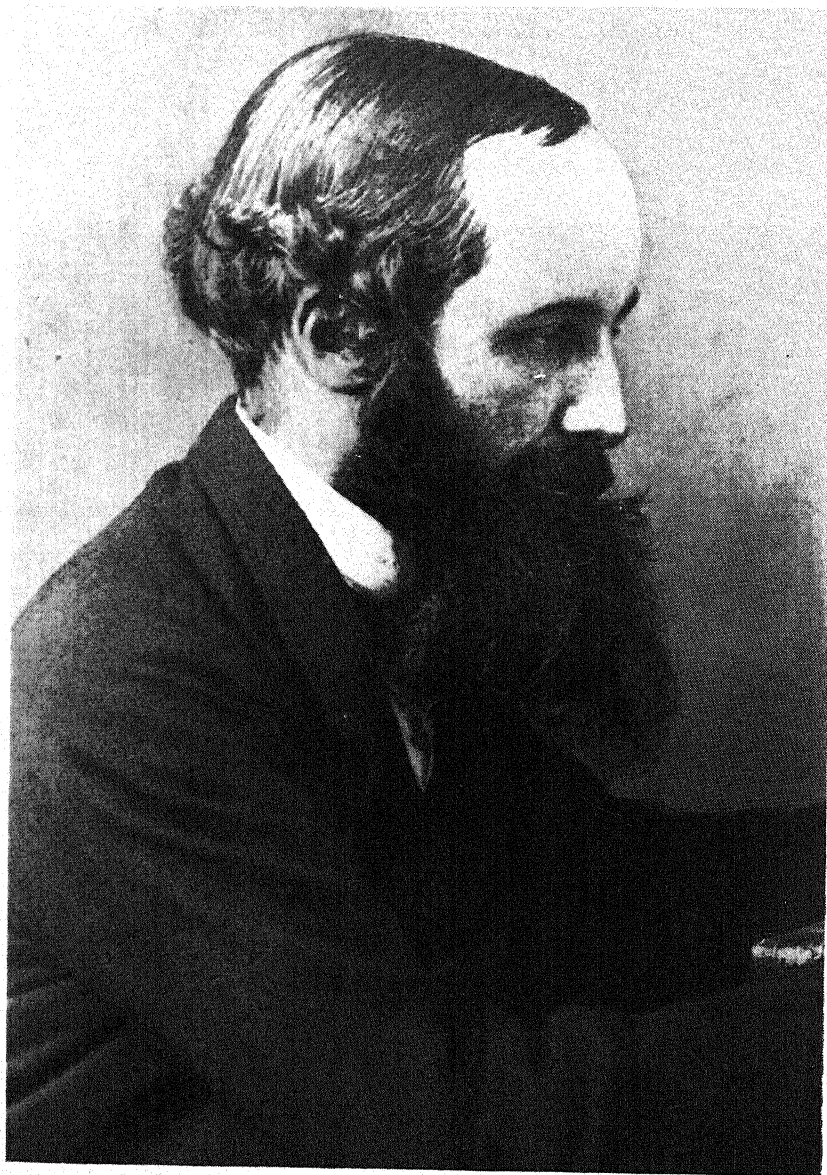


COLOUR CINEMATOGRAPHY

By the Same Author

COLOUR-MUSIC: THE ART OF LIGHT





Prof. James Clerk Maxwell, F.R.S. (1831-1879),
Founder of the Science of Colour Photography.

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COLOUR CINEMATOGRAPHY

By

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PREFACE TO THE THIRD EDITION

THE production of a book of this kind in England since the war has indeed become a formidable task. Each stage is completed only after such serious delay that revision at one time providing reasonably up-to-date information becomes quite inadequate long before a book goes to press. The adverse conditions under which the British publishing industry labours are the writer's excuse for the untidy final state of this treatise. Revision was completed in 1946 and during the ensuing four years of delay much additional information had to be added or inserted in order to cover the contemporary situation at the eventual time of publication.

Significant advances in the technique of motion picture colour film during the last ten years are without exception the outcome of chemical research. All important processes, other than Technicolor, stem from the concept of the formation of coloured compounds (or their destruction) in the immediate neighbourhood of the developed silver image. So far such an approach necessarily involves several coated layers. The high cost of the manufacture of such materials has so far kept the price of colour film too high to admit of its universal adoption, nevertheless the proportion of colour films made has steadily risen in recent years. It is difficult to conceive that there will be any sensational advance on chemical lines during the next few years. On the contrary, one good reason for expecting invention to shift its point of departure once more from the chemical to the physical is that the technique of television in colour will in due course bring about entirely new electrical methods of both recording and reproducing coloured images. There is nothing fantastic in supposing that the whole chemical basis of the photographic record may be already on its way to the museum, in which case the contents of this book will have become of little interest.

The public history of "processes" of colour cinematography is on the whole discouraging and disconcerting, but the reader may be assured that the private history is hardly credible, and will, if ever it be made known, constitute a singular commentary upon the least rational aspects of our society and its culture. At times the scientist must suffer a fit of discouragement when he contemplates the achievements of the colour film in the world of entertainment. Must all that analytical prowess, all that mathematical æsthetics, end as coloured plastic buried in the vaults of the British Film Institute?

When the names of the pictures in a catalogue and the numbers

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on the cans are all that remain, it is stimulating to ask why the golden light of a four by six inch Turner water-colour will outlive and outshine the once famous "glory" of the film. We must console ourselves by supposing that the true reward for the pioneers came and will come in the educational field, in medicine and the sciences, and in the domestic record.

The writer's personal view is that the æsthetic content of the art of colouring in films has so far been of a very low order. In the so-called fine arts the use of colour as a means of emotional expression has only very rarely achieved great significance, but there are certain Persian rugs and embroideries, and some Chinese ceramics, in which the colouring has for the trained observer a singular nobility of sentiment comparable to that conveyed by music. But these were not the creations of ordinary men, they were the supreme efflorescence which crowned the tradition of a thousand years, the end-product of an evolutionary process which began in the tents of nomads and ended in the palaces of enlightened monarchs.

But why should we castigate the makers of films measured to the cultural level of the average citizen of the democracies for lacking values which have never been assessable by more than one in a thousand? The film show is a commodity, like ice cream, prepared to titillate the jaded anatomies of pert shop-girls. The film is ersatz life, the final ignominy in a doomed civilization, the last shadow with its writing upon the wall. We are here concerned with the art and science of casting moving coloured shadows upon a dead screen in such a manner as to deceive the eye by simulating reality. But perhaps these shadows have no more and no less substance than that reality they set forth to reproduce, in which case our rather superior scorn is hardly justified.

The author acknowledges his debt to nearly every firm engaged in manufacturing or processing colour film, and to many technicians. Particular acknowledgments are due to the following firms, all of whom have provided data or given their permission to include extracts, or to reproduce figures and illustrations, from papers: Eastman Kodak; Kodak Limited; Du Pont de Nemours; Ansco Inc.; Technicolor Inc.; Photo-Produits Gevaert; Dufay-Chromex Limited; Gasparcolor Inc.; The General Electric Company, U.S.A.; The National Carbon Co. Inc., U.S.A.; Mole-Richardson Inc.; The Morgan Crucible Company Ltd.; Cinecolor Inc. Permission has been courteously granted by the Society of Motion Picture and Television Engineers, U.S.A., and Ansco, to reproduce certain papers complete. If permission has not been obtained in every instance of quotation, especially from the *Journal of the Society of Motion Picture and Television Engineers*, the author apologizes both to the Society and to the authors, but effort has not been spared to refer the reader

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to the source in every instance. The same remarks apply in many other cases, as in a work of this type the compilation of extracts from existing papers and published material in every form is inevitable. In previous prefaces acknowledgments have been given to the Controller of H.M. Stationery Office and to the Controller of H.M. Patent Office.

Finally the author expresses his gratitude to Mr. Sydney Groom, B.A., of the Science Museum, London, for his patient reading and correction of the proofs, and to Miss Joan Crawford for typing the manuscript and compiling the index.

ADRIAN CORNWELL-CLYNE, M.B.E.

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THE time has at last arrived for the delicate instrument fashioned by so many unrewarded and unhonoured pioneers to be handed over to the directors of films, to the producers, and their army of assistants, technical and non-technical—for them to use as their talents and their inclinations permit. Cinematography in colours has taken thirty years to bring to its present stage of technical development, a stage which it is admitted at last makes practicable commercial production on the grand scale. Men of many nationalities contributed to the solution of the problem. Fortunes have been spent by private individuals. Millions of pounds have been invested by the general public. (Probably not less than three, and perhaps five million pounds.) Yet there has been little to show for all this effort. We know that the pioneers could not have been successful until subsidiary problems had been solved which had a direct bearing upon the main research, and these were problems of great difficulty. The speed of emulsions had to be multiplied by a hundred, new sensitizers had to be discovered by the photo-chemist, and studio illumination had to be enormously increased before there was the remotest likelihood of making films in natural colour practicable.

The history of invention teaches us that progress is rapid and continuous when once the right way to do something has been revealed. It is like climbing an entirely unknown mountain—half the battle is won if we can choose the most practicable route. There were so many attractive short-cuts to mislead the early workers who sought to achieve cinematography in colours. For example, it is likely that all the work lavished upon the “additive” method of synthesis, in which three separate images in the primary colours are projected in superposition upon the screen, was wasted, though for many years this appeared to offer a simple and elegant solution.

The æsthetic and technical problems which the artist must solve in the colour film are of greater complexity and difficulty than in the art of painting, so that it is likely that masters and masterpieces will be still rarer. In the art of painting there have been few great colorists. It is true that the film colorist is freed from the irritating difficulties of manual craftsmanship. He is free to compose mentally, while applied physics and chemistry are ready to obey his subtlest directions—nevertheless, the powers of mind demanded are of a higher order in so far as colour composition *in time* adds another dimension to the geometry of his imaginative conception. Vulgarities are invariably the outcome of the gift of self-expression which applied science has by various instruments given the lazy and shallow minds of entertainers.

Is there a film art? Or is the film entertainment? Is entertainment art? The reply to the last question is, that entertainment is *not* art. But the film, it can be argued, could partake of the nature of fine art; and films have been made which are undoubtedly works of art. But is any purpose served by discussing the creation of a film as one discusses the creation of a picture, or a symphony? From the standpoint of the producer of successful films it is a waste of breath, and a producer of such films would be the first to assert that the categories of art are by the nature of the case inapplicable to the commercial film. It must follow, therefore, that the commercial producer is interested in technical principles of colour composition as an additional specialist aspect of film production only in so far as such principles can enhance the selling power, and the booking power, of a film. Indeed, the principles of coloration, which, if followed, would ensure the æsthetic balance of a film, might come into actual conflict with what can be referred to as its commercial quality. The conflict between the conditions of a work of art and of commercial success is absolutely fundamental, and only fools deceive themselves in this matter. If any producer hesitates between the demands of Heaven and Mammon, he will fall into the ready pit of liquidation which lies yawning between the two.

The cartoon film is the last remaining hope of the highbrow. In this film-form we actually approach the conditions of a work of art. Imagine the possibilities of this *genre* in the hands of a very great artist! Walt Disney has exquisite wit, and fantasy,

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and caprice, and at times a singular delicacy, an almost feminine tenderness of perception, but from the time he introduced colour into his films to the present moment he has failed to bring his colour as an expressive factor up to anything like the level of the rest of the work—the animation, and the pictorial invention. But he is learning to be a colorist by degrees, and we may yet see some unforgettable colour, that is, colour which, by its emotional intensity, and by its significance, makes a permanent contribution to our imaginative life.

Whatever we may say about colour composition in an art in which movement is a factor, we must observe the truth that as an expressive factor colour in itself must be subordinate to other factors which we recognize as outstanding in the talking picture. It is in the lack of recognition of this subordination that some of the worst mistakes will be made in the early history of the colour film. Because, unless the coloration actually contributes some further value to the power of the impression made upon the mind by the film as a whole, its presence is unnecessary, and even disturbing and undesirable.

It has often been observed that the addition of sound to the film altered the evolution of the art of the film radically. It is beyond dispute that that is what actually occurred. Although purists have never since ceased criticizing the fact that visible movement was the film's principal expressive means, and that sound must always be subordinate to vision, the films of the last few years have made the sound only slightly less important than the visible action. In the film "One Night of Love," which was the more forceful, the singing of Grace Moore, or the pictorial background? The sounds of Grace Moore's voice were so lovely that they would take precedence of almost any visible aspect. Note that "One Night of Love" was an extremely successful film. This increasing value of the sound factor is likely to receive further support from the series of pictures which are about to be made of operas. How can the visible movement, the pictorialization, of an opera possibly possess a value above that of the sound?

The ideal artistic conditions can only exist in some synthetic art of the future such as that fully discussed in the writer's *Colour-Music: The Art of Light*. In the meantime the sound-film is a hybrid as an art-form. On some occasions the sound may be the more important factor, and in others the picture. But the point is, that introduced into the film in its present form colour cannot take precedence in the storytelling of either the action or the sound. It can only assist. How can it assist?

1. It can induce a mood in the observer.
2. It can concentrate attention upon some one area in the picture plane.
3. It can assist the impression of sequence—the approach to crises, and the recession therefrom.
4. It can emphasize, or even bring about an increase in the illusion of spatial depth—the third dimension—by aerial perspective, and the plasticity of the warm-cold hue opposition.
5. By appeal to one of the four types of psychological perception¹ it can provide subjective comment on the dramatic situation.
6. It can heighten generally the sentiment of reality owing to the fact that normal vision includes the sensation of colour.

The rarest characteristic in the commercial films of the day is restraint. In so far as colour offers to the director a powerful means of emotional enforcement, it inevitably follows that the unthinking film-maker, forthwith, in the first film in colour he has an opportunity to make, proceeds to exhaust the chromatic palette in a crazy and ill-considered attempt to tell the public that he has discovered colour—"colour in all its rainbow glory"—and so forth. But telling a film-maker to have restraint is rather like telling a racetrack driver not to "step on it." He considers it his business to do so. And most film directors want to ram their ideas home with a mallet. They are convinced that the people are so doped, and drugged, and tired, and ill, that it is necessary to give them a violent stimulant in order to awaken their attention. Or they suppose that they want films to have precisely the opposite effect—namely, that the masses are presumed to be so nerve-racked by modern town life, and so pestered by the appalling difficulty of keeping their heads above water, that a soporific and soothing drug will earn their undying gratitude.

¹ The four perceptive types, according to Bullough and Myers, refer their experiences to the Objective aspect, Physical aspect, Associative aspect, Character aspect.

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It is all but hopeless to suppose that when colour comes to be generally used the producers will exhibit any restraint at all. Already the tendency is for colour to be used, in the few films which have been made, in a gamut pretty much like that of the advertisement hoardings. The first inspiration the art director has is to use red—pure and unadulterated spectrum red, generally contrasted with bluish greens—the simplest and most obvious of complementary intervals. But let us hope this is only a temporary stage in the evolution of the film colour sense. It will take very great skill to control the colour so subtly that the audience is hardly aware of the presence of colour in the picture, save in those moments during which the director wishes the audience to concentrate on some colour incident *as colour*.

This book is an attempt to make a broad survey of the territory which the pioneers have explored. We are now in a position for the first time to forget experimentation, and to make use of colour as a contribution towards an end—and that end, we should always remember, is the making of a *good film*.

In the film world there is such a woeful lack of knowledge of fundamental principles, such inability on the part of those who should know better to judge rightly of the relative merits of many so-called new processes, that it is high time there was made available a reliable treatise on the subject of colour cinematography. An endeavour has been made to meet this requirement.

There is no attempt to present more than a summary of the history of the subject. For detailed treatment the reader is referred to E. J. Wall's great work, *The History of Three-Colour Photography*. The object has been to give the reader a reliable description of processes now being worked, and to give a simple outline of the principles upon which all systems have been based.

The writer's acknowledgments are due to the Controller of H.M. Stationery Office and to the Controller of H.M. Patent Office for permission to reprint extracts from certain patents and to reproduce some of the figures in Special Report Series, No. 139, of the Medical Research Council, London. Permission has also kindly been given by the Editor of the Journal of the Society of Motion Picture Engineers to reproduce certain diagrams and to reprint extracts from technical papers. Messrs. Taylor, Taylor & Hobson, Ltd., the Editor of *Nature*, and Mr. H. W. Lee have given their consent to the reprinting of the interesting account of "The Lenses Employed in the Technicolor Process of Cinematography." The assistance given by many firms engaged in exploiting colour processes has been very valuable. Where the information regarding a process is scanty, or perhaps inaccurate, this is due to the unwillingness of the owners of the process to divulge information.

LONDON, 1936.

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DURING the two years which have elapsed since the first publication of this book, no new process of colour cinematography has been made commercially available which can claim to be novel in any fundamental respect. The Agfacolor 16-mm. monopack has provided an attractive addition to the colour films available in the substandard market. The processing is very simple since the three subtractive primaries are simultaneously formed in the three layers during the development of a reversal image, all silver being removed afterwards. Statements have been made that this interesting product will be available shortly for 35-mm. motion picture work and that copies can be made satisfactorily.

The period has been remarkable for patent activity, particularly in the monopack and lenticular fields. Eighty or more patents cover the concentrated German attack on the problem of copying lenticular film. Dr. Bela Gaspar has also been very active, with about thirty new patents covering, mainly, proposals for monopack negative film, methods of copying, and colour-development. I. G. Farbenindustrie Akt. Ges. have covered various aspects of colour-development in some ninety patents, and that Kodak have been working in the same region is evidence by over forty new patents.

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In 1939 we find three processes sharing the bulk of the world's demand for professional motion picture 35-mm. colour film—Technicolor, Dufaycolor and Gasparcolor. The progress made by Dufaycolor has been very rapid since the first successful proof of negative-positive processing when the Coronation film was released. The remarkable simplicity of Dufaycolor, the photographic technique being substantially identical to black and white, has contributed to its popularity, for in many respects this product fulfils the practical requirements which motion picture engineers had long ago formulated.

Inventors still contribute new optical combinations for beam-splitting, but the perfect functioning of a prism is not made more likely by the multiplication of its parts, though it is in this direction that new efforts seem mainly to tend. Among other prismatic proposals we might mention V. Hudeley's (E.P. 444,051). This prism belongs to Classification 3D (see page 537), there being three objectives behind a prism system and three sub-standard pictures in the space of one normal frame. Further patent on the Brewster camera is E.P. 450,673. Two-colour beam-splitters reminiscent of Raycol re-emerge in Thomas and Bryan's E.P. 453,221. One would have thought it late in history for this species of two-colour additive process. The very complex prism described in Bellingham and Stanley's E.P. 459,664 was designed in accordance with the writer's requirements, for Gasparcolor, in 1935. A certain amount of practical work was accomplished, but it was found extremely difficult to retain perfect registration of the enlarged sub-standard negatives, even though the originals were quite free from parallax errors. This prism is used in conjunction with Bellingham and Stanley's E.P. 451,274, which covers an ingenious arrangement of the three sub-standard frames spread over two normal frames. A. H. Kamfer proposes to take (E.P. 469,359) and project (E.P. 478,766) four colour sub-standard records in successively exposed pairs. L. Klaver describes a four element prism cemented cube giving images on three films, the divider being behind the objective (E.P. 472,468). A. B. Klein patented a similar beam-splitter in E.P. 475,415, with colour filters introduced within the block "so that any stray light reflected from a portion of the prism lying beyond the reflecting plane responsible for the formation of a lateral image will, when finally emerging from the face of the prism adjacent to the plane in which the said image is to be recorded, be minus light which the recording filter is capable of transmitting, or, if a photographic emulsion is used, which does not require such a filter, which the emulsion is capable of recording." This prism works very well indeed. It is doubtful, however, if a camera will ever be made to accommodate it!

W. H. and E. C. Harrison describe a two-colour beam-splitter in E.P. 473,782. The arrangement shows a semi-transparent mirror and a prism in front of a pair of sawn-off objectives providing the usual two sub-standard negatives within the area of one normal frame. Further Hillman patents are E.P. 478,500, 478,501, the latter dealing with additive three-colour projection: more lately he has turned his attention to three-colour beam-splitters of considerable complexity, E.P. 483,817, 483,819, 483,820, 494,333, 494,334. L. Horst would take (E.P. 485,190) three-colour records side by side across the film, surely an unnecessarily difficult procedure.

Pairs of colour-record images arranged side by side and side uppermost are provided by a complex beam-splitter patented by Cosmocolour Corporation, E.P. 489,333 and 474,800. The arrangement on the film is the same as the Busch process (see page 268). Cosmocolour is a two-colour subtractive process of normal type, using for the print a double-coated positive stock. Presumably the sub-standard records are enlarged by an optical printer and the images toned by a variant of the organic or inorganic toning methods. It is reported as being the invention of Otto C. Gilmore.

From all this new effort devoted to the design of beam-splitters very little seems to have emerged so far. One comes to the disagreeable conclusion that many variants on additive propositions which have long since been proven impracticable are devised, or resuscitated, with the conscious object of defrauding one of that singular species of mug who seems to hover always in close proximity to colour photographic development. One doesn't know whom to be most annoyed with, the confidence trickster or his gaping victim. There is certainly no necessity to be sympathetic about the latter's loss of money, when there was always the Royal Photographic Society at his elbow ready and willing to give the names of reliable scientific advisers.

The early pioneers anticipated tremendous enthusiasm from the general public, they supposed that the black-and-white film would forthwith cease to exist as a result

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of the successful solution of the technical problem of cinematography in natural colour. We know now that things did not turn out in exactly the way in which it was anticipated that they would. To-day, in 1939, there is nothing like unanimity in the reaction to colour of the individual members of audiences. Where colour sensation is concerned, everyone is an expert. To tell someone that the colour of some part of a familiar image is rightly reproduced when he thinks it does not correspond to his normal visual experience, is to insult him, if we can judge by his reaction on these occasions. He is as unquestionably entitled to assert that there is something wrong with the colour, as he would be to observe an apparent distortion of form. Yet colour technicians unhesitatingly accuse him of lack of knowledge or of faulty observation. Now such accusations are only justifiable provided that we assume an awareness on the part of the audience of the exact physical and physiological limitations within which the colour motion picture must continue for many years to function. The average member of the audience cannot be expected to be aware of the nature of the "convention" he is requested to accept as representative of reality, and from this state of affairs there arises a serious conflict which we are at present incapable of resolving.

The recognition of the curious transformation which the original has undergone usually takes the form of doubt as to its accuracy; which is only what we should expect, the addition of colour to the image being assumed to be a further stage towards the achievement of *visual illusion*.

The reaction of different individuals to the colour film is material of immense interest to the psychologist. Those of us who are daily brought into contact with the irreconcilable opinions of people who view colour films, find ourselves alternating between a state of puzzled irritation and surprised wonderment depending upon whether a shot is condemned for being on the one hand too blue, when we know it to be accurate, or on the other hand praised as being marvellously good when privately we are aware that it is positively wrong.

Painters are the most satisfactory people of all to whom to show colour films. They are always appreciative and never critical of the illusion failure. For them the colour of a film is not examined as if it were there to be measured or "checked up"—it is "nice colour," or "interesting colour" or "poor colour"; but never, or hardly ever, "true colour" or "wrong colour." Whereas for film directors, producers, distributors and exhibitors it is always "all wrong," and that generally when everything has behaved about as well as it can be expected to in the state of existing knowledge.

Most cinema-goers seem to agree that the colour film is more "real" than the black-and-white film, although they generally mention that, of course, they are not referring to "those awful early colour films," but to the most recent ones. The simplest conditions of artistic unity, theoretically, at least, required the coloration of the monochrome image, because the extreme realism of the sound representation conflicted with the entirely artificial nature of the visual image. Only the exceptional observer, generally an artist, is capable of an analysis sufficiently penetrating to be aware of the fact that the colour film may fail to achieve the increased realism hoped for, and that the addition of colour constitutes a move backwards towards the conventional limitations of the silent film; a move, in fact, away from realism towards the terms of an art form. But such preoccupations with aesthetics will never be in the mind of the average cinema viewer. For him the colour film is more real. If he is not entirely satisfied it is of interest to put forward the probable reasons for the vague feeling of uneasiness which the projected image seems to cause many people. To understand the problem properly, it is essential that the student should be aware of the fundamentally different stimulus originating from the screen as compared with that derived from vision of the normal three-dimensional world.

The principal differences are these:

1. The upper limit of perceptible brightness difference in the image derived from a natural exterior may be hundreds of times greater than that of the screen image. On the other hand, the threshold has moved up, so that the length of the total contrast scale may be the same proportionately. The psychological effect of a high brightness level of adaptation is, however, not identical to that of a low level, quite regardless of the differences perceptible in the contrast scale at any given adaptation level. In other words it does not matter whether one can see a limit of one hundred degrees of difference in a brightly lit exterior

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and one hundred degrees of brightness difference in a poorly lit screen—the former visual experience is quite different. Regardless of adaptation, the exterior still “feels bright,” and the poorly lit screen is “gloomy” (qualitative effect).

2. The screen image is non-stereoscopic.
3. There is distortion in colour rendering (density differences recording colour differences) at the “upper” and “lower” limits of the photographic record. By rapid “local” adaptation the eye can appreciate local colour in shadow areas under natural conditions of vision. No visual apparatus can correct a distortion.
4. The reproduction range of colour must be restricted to the trichromatic coefficients of a given set of reproduction primaries. The area on a chromaticity diagram enclosed by these primaries will only comprise a part of the totality of colour perceptions.
5. As the eye by muscular movement is caused to receive on the fovea the varying stimuli originating in the exterior three-dimensional field, a range of sensation differentiation is perceived which is much greater than (and qualitatively different to) that derived from a two-dimensional screen-image source of relatively low brightness, providing in the retina a correspondingly low adaptation level.
6. The contrast of the illuminated screen area, perhaps just filling the fovea, against the black surroundings is a visual experience bearing no relation to images of the normal world. It is analogous to observing the outer world through the mouth of a cave.
7. The telescoping of the brightness range results in distortion of colour which arouses psychological dissatisfaction. Blue skies seem too dark and too blue, shadows too black and empty.

The errors of judgment to which can be ascribed many defects are peculiarly likely to be encountered by manufacturers of special film stock for colour cinematography. Clearly, the conditions of sale of a sensitized product in the open market make it impracticable for a manufacturer to provide a staff of technical nurses waiting to sit by the side of every cameraman who has purchased a few feet of film. Nevertheless the extreme care that the Technicolor authorities have exercised to ensure that nobody shall be permitted to use the special camera equipment without supervision and control has been the key to the high standard achieved by this process.

Were it as easy to spot errors in the photographic technique of monochrome as it is in colour, the audience would be much more critical of photography than they are. They are at present quite incapable of remarking any quality in particular in so far as photography is concerned, for the level of the photographic technique is frequently so low that were an emulsion chemist to find himself in the audience he might be excused from wondering why he should have slaved for years to provide this thankless industry with that miracle of applied science, the modern high-speed motion picture film negative, or for that matter with an equally perfect positive material. It is instructive and curious to reflect upon the fact that the smallest error is magnified in colour work into a considerable catastrophe, the error being glaring to the least intelligent of the audience, and that henceforth the technician will not be able to hide his incompetence behind a foolproof film. Unfortunately, for some time to come the manufacturer will probably be blamed for all misuse of his product—until such time, in any case, as will serve to prove that certain operators invariably obtain first-class results, while others as certainly fail.

The colour direction of films in the last two years leaves a lot to be desired. Technical advance has outdistanced the ability to exploit fully the æsthetic potentialities. Commercially minded producers are unlikely to appreciate that they are now the owners of an instrument which only trained artists can perform upon, and for this reason little work has been done which manifests even intelligent application of colour science, much less the inspired imagination of creative art. It may well be that it is hopeless to seek for anything really new and thrilling from a form of entertainment primarily intended for millions of untrained and careless observers. Yet it is a great pity that so few men or women of developed taste and artistic culture are engaged upon the design of films.

If not remarkable for practical advance, the last two years are very important in

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the history of colour cinematography for the reason that during this period there has been laid down a permanent foundation of theory upon which it is fairly certain all structures of the future will have to be built. For this work all of us interested in this field are indebted to Prof. A. C. Hardy, whose *Handbook of Colorimetry* and *Theory of Three-Colour Photography* are of the first importance, and the same is true of *The Theory of Additive Three-Colour Photography*, by Dr. G. B. Harrison and Mr. R. G. Horner; also *Analysis Filters in Colour Reproduction*, by Dr. D. A. Spencer and H. D. Murray.

The C.I.E. Distribution Coefficients are given in this edition on page 241, and a résumé of the methods of evaluating the chromaticity co-ordinates of a colour by use of the tables given in Prof. Hardy's *Handbook of Colorimetry*.

The author is much indebted to Mr. Sydney Groom, B.A., of the Science Museum, South Kensington, London, for some very helpful "Notes on Calculations relating to Filters for Three-Colour Photography," which by kind permission have been now included. (See page 124.)

LONDON, 1939.

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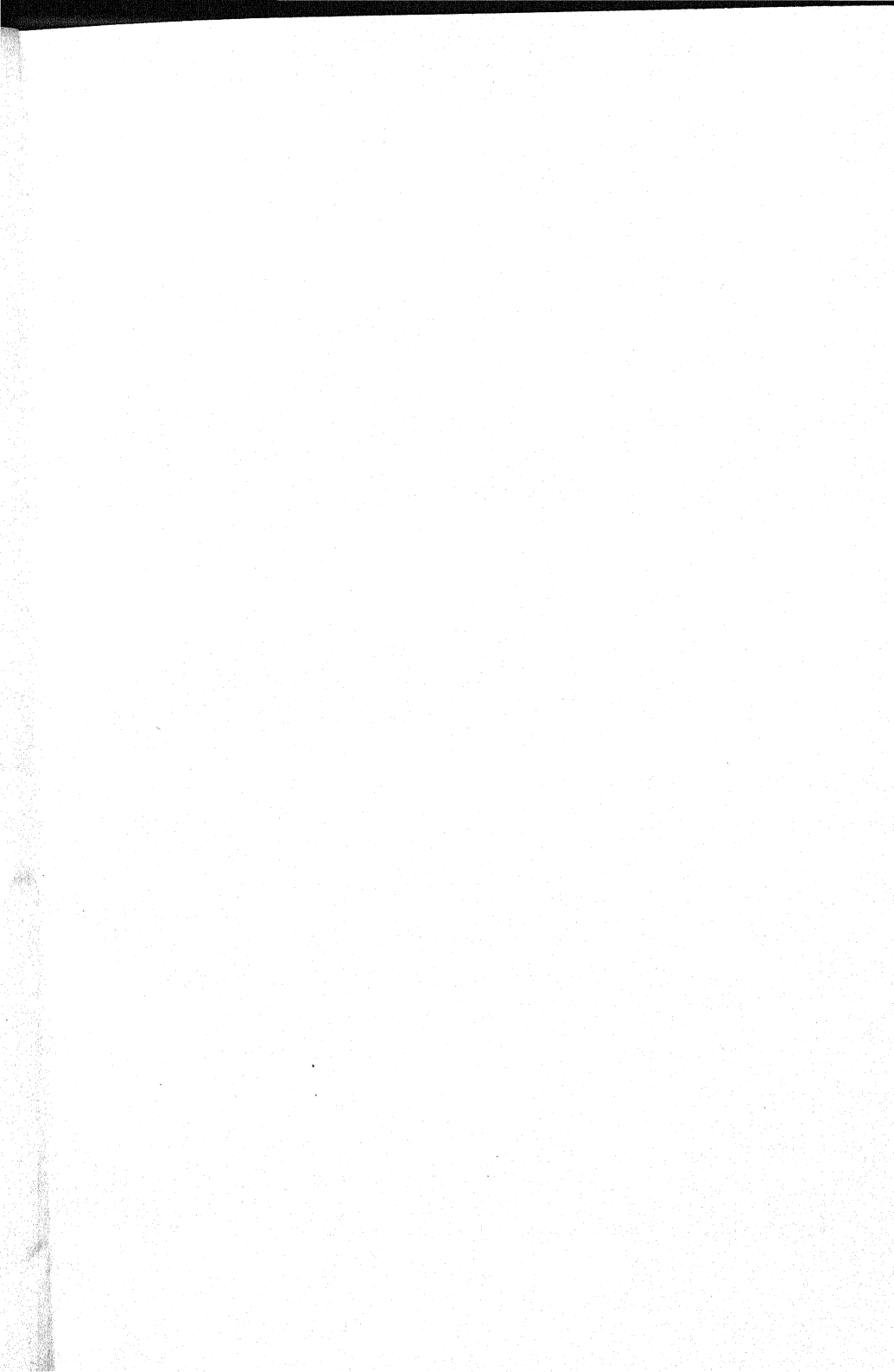
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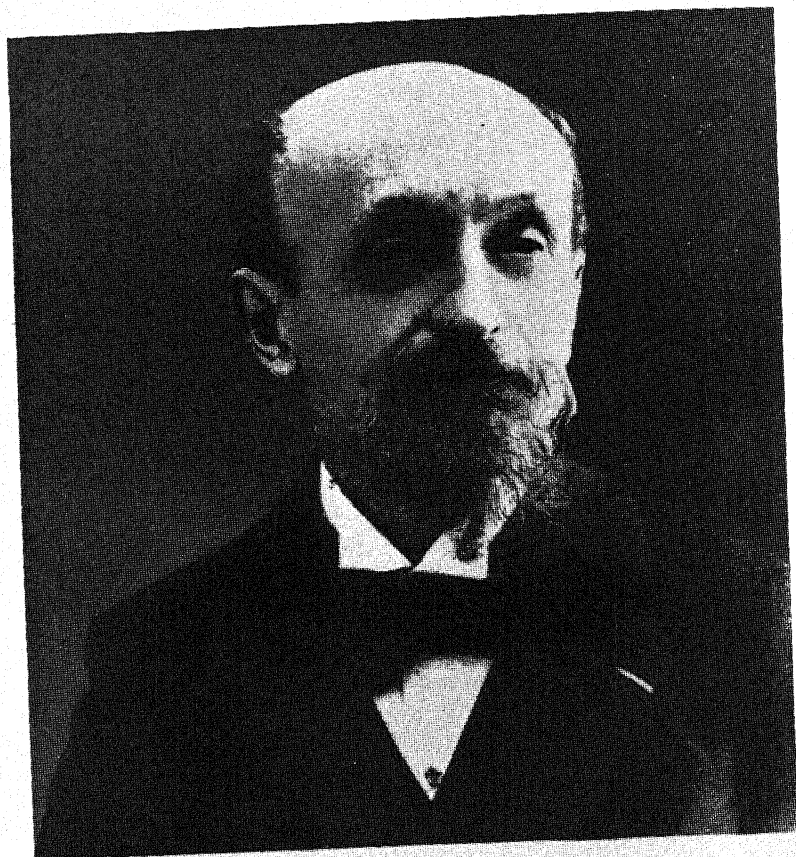
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Louis Ducos

Duhauron

FIG. 1.—Louis Ducos Duhauron. French Inventor. In 1869 he described in great detail every aspect of the territory the rest of us have since wandered about in. A first-class genius who died, as other prophets have died, unhonoured and unsung.

PART ONE

The first idea of method is a progressive transition from one step to another in any course. If in the right course, it will be the true method; if in the wrong, we cannot hope to progress.

COLERIDGE.

Historical Summary

1672.—Newton's communication to the Royal Society led directly to the first formulations of the three-colour theory of colour vision [1].

1802.—Dr. Thomas Young [2], in his famous paper read at the Royal Society in 1801, propounded the theory that there must be three types of optic nerve fibre¹ to account for the phenomena of the admixture of coloured lights, which had originally been observed by Newton. This was the origin of the so-called trichromatic theory of colour vision.

1855.—Helmholtz developed the mathematical treatment of the theory [3], and Clerk Maxwell [4] was the first to conceive how these principles might be applied to photography for the reproduction of the colours of Nature (*Proc. Roy. Soc.*, 1855). He said: "This theory of colour may be illustrated by a supposed case taken from the art of photography. Let it be required to ascertain the colours of a landscape by means of impressions taken on a preparation equally sensitive to rays of every colour. Let a plate of red glass be placed before the camera and an impression taken. The positive of this will be transparent wherever the red light has been abundant in the landscape and opaque where it has been wanting. Let it now be put in a magic lantern along with the red glass and a red picture will be thrown on the screen. Let this operation be repeated with a green and a violet glass, and by means of three magic lanterns let the three images be superimposed on the screen. The colour of any point on the screen will then depend on that of the corresponding point of the landscape, and by properly adjusting the intensities of the lights, etc., a complete copy of the landscape, as far as visible colour is concerned, will be thrown on the screen."

1861.—In a later lecture Maxwell gave a demonstration, and reproduced the colours of a bow of ribbon with some approximation to truth (*Proc. Roy. Soc.*, 1859, 60, 10, 404, 484; *Brit. Journ. Phot.*, 1861, 8, 272).

1862.—The French inventor Ducos du Hauron in 1862 described a "Mélanochromoscope" (an optical instrument for the additive admixture of three primary colour images), additive projection, the mosaic screen process, bipacks, and even tripacks; thus he anticipated nearly all subsequent practice. The Académie des Sciences refused

¹ Known today as "the three-response hypothesis."

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to allow the presentation of the paper. Indeed, it was not published until 1897 [5].

1869.—In *Les Couleurs en Photographie, Solution du Problème*, Paris, 1869, he describes additive tricolour projection.

Charles Cros was prior to F. E. Ives in the design of chromoscopes (*Compt. Rend.*, 1879, **88**, I, 121), and in a paper in *Les Mondes* (February 25, 1869) he discusses analysis by successive and simultaneous admixture. This is the first suggestion which ultimately was realized in the motion picture additive colour processes. He proposed to accomplish synthesis by persistence of vision with the aid of the phenakistoscope or the zoetrope.¹

A friendly controversy between du Hauron and Cros appeared in *Cosmos* (July 1869); and they both agreed that, though working independently, they had deduced the same results from the same principles. Both men described the solutions known as additive and subtractive.

It is curious that Clerk Maxwell does not seem to have mentioned the relation of the subtractive colours to the taking, or analysis, colours.

Among others who advanced the science of three-colour photography in the nineteenth century were:

F. E. Ives.

A. von Hübl.

A. Lumière.

Sir William Abney.

H. W. Vogel.

L. Didier.

E. König.

J. Joly.

J. W. McDonough.

A. J. Newton.

Howard Farmer.

E. Sanger-Shepherd.

A. J. Bull.

1897.—The commercial success of black-and-white cinematography, which was the outcome of the inventions of W. Friese-Greene, naturally soon led to the proposal to make moving pictures in natural colours.

The earliest patent is that of H. Isensee of Berlin (D.R.P. 98,799,

¹ *Phenakistoscope*.—Toy invented by Plateau. A cardboard disc perforated at equal distances round the periphery by small slots. One side of the disc is blackened and on the other a series of images is arranged representing men or animals in the various attitudes which correspond to the successive phases of a movement. When the disc is spun round on its axis opposite to a mirror and the eye applied to the blackened side on a level with the revolving slits, the reflections of the various images are seen one after another corresponding to the different attitudes assumed by the original object.

Zoetrope.—A cylindrical chamber revolving on a vertical axis. Narrow upright slits were made round the brim and inside the cylindrical wall a strip of paper was pasted on which a series of images was arranged so as to represent the successive attitudes of a man or animal in motion. If these figures were observed through the slits while the zoetrope was revolving the same impression as that caused by the phenakistoscope was produced.

December 17, 1897). He says: "By means of this invention the projection images should appear to the eye of the observer in natural colours by means of the images being projected rapidly one after the other and in regular sequence in the colours red, green, blue. For this purpose there is placed eccentrically before the objective a disc with three sectors of red, green, and indigo-blue glasses. From the negatives, positives are made, and projected by the series apparatus. In the well-known analogous process for the reproduction of coloured images, for instance, with Ives's 'Heliochromy,' three different coloured images of one object are formed at one and the same period; here different coloured images follow in successive periods in sufficient rapidity, and there is formed in the eye of the observer a moving picture in natural colours."

1898.—William Friese-Greene, then living in Brighton, described in rather vague terms an impracticable method by which a lens was divided into three sectors, or a *rotary shutter* might be used (B.P. 21,649, 1898). He appears to have used a single plate and a single image. The rotary colour shutter was significant, but this had been anticipated by Isensee. A demonstration was given at the Royal Photographic Society, February 27, 1900 (*Brit. Jour. Phot.*, March 2, 1900).

He was the victim of a good deal of heckling, but he said he was not unused to the adverse criticism of early ideas with regard to an invention which had been received years afterwards with popular approval. He quoted some of the remarks which were passed upon his introduction of animated photography, of which he was admitted to be the originator.

Apparently, associated with W. Friese-Greene, in the same year, Captain William Norman Lascelles-Davidson, also of Brighton, patented a triple-lens motion picture camera (B.P. 23,863, 1898). The colour filters revolved either behind the lenses or just in front of the film, or the diaphragms might revolve, or slide synchronously with the film, or with the positive in a similar projector. This camera anticipated the work of Frederick Marshall Lee of Walton and Edward Raymond Turner of Hounslow,¹ to whom is usually accorded the credit of achieving the first practical results in additive projection. Their experimental work was financed by Charles Urban, a well-known impresario and showman of the day. Records were made in a camera with a single lens equipped with rotating filters of red, green, and blue. Projection was attempted with three lenses vertically disposed.

¹ F. E. Ives said (*Trans. Soc. Mot. Pic. Eng.*, 1926, No. 25, p. 74): "The first recorded suggestion is the British patent of Lee and Turner, two young men who were employed in *my workshop* in London, and who with my consent patented a scheme *which I disclosed to them* but which I told them was of more theoretical than practical interest at that time. I considered it a great joke when their patent rights were afterwards sold for real money; but, as I predicted, the method was not practically satisfactory."

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Apparently each picture was projected through each of the lenses in turn, and three pictures always projected simultaneously (B.P. 6,202, 1899). This scheme in some respects anticipated Hillman's two-colour arrangement. Time-parallax was inevitable, and considerable fringing must therefore have been present.

1900.—W. Friese-Greene patented a lantern for three-colour additive projection.

1903.—Dr. Benjamin Jumeaux and W. N. Lascelles-Davidson devised three-colour projection apparatus described in B.P. 3,729, 1903; 7,179, 1904; 27,419, 1904.

1905.—Otto Pfenninger of Brighton (in B.P. 322, 1905) invented a projection lens and prism of doubtful practicability. Friese-Greene's B.P. 9,465, 1905, was equally hopeless.

About this time inventors became doubtful of the possibility of three-colour additive projection, as they always encountered fringing effects due to space and time-parallax.

1906.—Then we come upon the name of George Albert Smith, F.R.A.S., of Brighton, who in B.P. 26,671 of 1906 patented the method which eventually was commercialized as "Kinemacolor." In this patent he proposes to substitute *two colours* for the three which everyone had been trying to get. Alternate red and green filters were rotated in front of the lens. Double the usual number of pictures were taken—namely, 32. Smith mentions projection at 30 pictures per second. In a lecture delivered at the Royal Society of Arts (December 9, 1908) he remarks that two colours seem to give a range equal to three. He exhibited a harvesting scene and a yacht race. The greys were said to be excellent. He said: "In 1902 I was invited by Mr. Charles Urban to assist in a thorough trial which he was making, regardless of reasonable expense, of a three-colour process (it was probably that of Lee and Turner, and perhaps of W. N. Lascelles-Davidson also). At that time little was known about the possibilities of sensitizing film to red and green, and to that extent we were handicapped. Nevertheless, in good sunlight we did succeed in taking a few negatives." He goes on to say that superimposition was found impossible; registration was terribly uncertain; and parallax troubles always defeated them. Simultaneous superimposition was first attempted (Lee and Turner), then successive projection. This was successful up to a point, but required high speed—namely, 48 pictures, or even 72 pictures, per second, which was entirely impracticable on contemporary projectors. The death of the original patentee (Turner) put a further damper on the enquiry. "During the last four years I have renewed enquiry," said Smith; "I take pictures with an Urban Bioscope Camera at 32 pictures per second. The present results are presented as early experiments in the photography of moving things in colour, and as the first serious exposition of work done in that direction."

1906.—W. Friese-Greene gave a demonstration at the Royal Institution, January 25. In this year E. J. Wall suggested imbibition printing and the subtractive synthesis as the proper solution to the problem. According to Wall, Jumeaux and Davidson were the first to apply the two-colour principle to the additive system. They are said to have exhibited in Paris in 1904 (B.P. 3,729, 1903). Their system was demonstrated by Captain Lascelles-Davidson and W. Friese-Greene at the Photographic Convention of Great Britain in Southampton, July 1906. The *British Journal of Photography*, July 27, 1906, says:

We have here applied to the lantern precisely the same principles which A. Gurtner of Berne has utilized in his two-colour process (the first practical bipack, D.R.P. 146,149, 1902). The real reds are ignored, and whilst this may be useful for pure landscape work, it can never be a true scientific record of colour by the aid of cinematography.

1907.—The *British Journal of Photography* of December 6, 1907, notes:

We have had an opportunity of seeing some results achieved by Mr. G. A. Smith of the Urban Trading Company, Rupert Street, in cinematography in colours, and whilst there is yet room for considerable improvement the progress made is extremely satisfactory. We were able to compare the colours in the pictures projected with some of the actual accessories used, and the rendering of the colours was strikingly accurate, particularly in the case of the reds. Only two taking and projecting filters were used, an orange-red and a blue-green, the usual third or blue-violet filter being dispensed with. Naturally the whites obtained are not pure, but have a slight yellowish tinge, yet when projected on the screen with brilliant colours this defect is hardly noticeable. The progress achieved is so satisfactory that we are warranted in saying that the process should be commercially valuable in a very short time.

1908.—Friese-Greene Patents Ltd. was formed. The capital was £2,400 in £1 shares. "To acquire rights of A. Ramsay from G. W. Chapman, W. Friese-Greene, and C. J. Harris."

This sum was perhaps the first money invested of the several million pounds which were to be invested in colour processes within the next twenty-five years.

In this year G. A. Smith exhibited at the Royal Society of Arts in December 1908 (*Journal Royal Society of Arts*, 1908, 57, No. 2,926).

1909.—We find in the *British Journal of Photography*, March 5, 1909:

The admission into the programme of the Palace Theatre of Varieties of the Smith-Urban cinematography pictures in natural colours marks another era in the application of photography to entertainment. The demonstrations at the House of the Urban Company, and more recently at the Royal Society of Arts, have shown the remarkable success of the method, and the eulogies which technicians have passed upon the process have been repeated with added emphasis by the press and public who have seen the projections from the auditorium of the handsome theatre in Cambridge Circus, which again leads the way in introducing to the public this latest triumph of the cinematograph.

Thus "Kinemacolor" was launched, the first colour process to be commercialized. The trade name "Kinemacolor" was registered

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by C. Urban (No. 333,708) by the Natural Colour Kinematograph Co. Ltd., Kinemacolor Building, 80-82, Wardour Street, London, May 17, 1911.

1911.—Many will recall the performances which now began at the Scala. The *British Journal of Photography* (April 17, 1911) notes that:

The programme of Kinemacolor performances opened on Monday last with a private view at which Messrs. Charles Urban and Albert Smith presented a most comprehensive . . .

and so on. There were, it appears,

farmyard and agricultural scenes, topical events, portrait studies, and a moving picture play, and growing flowers. The entertainment concluded with a spectacular play adapted from the German of Frau Luna performed some eight or nine years ago at the Apollo Theatre, Berlin. The promoters of Kinemacolor may be congratulated on having originated an evening of combined instruction and entertainment which is unique of its kind and should prove capable of taking its place among the established attractions of the London theatres.

This it did, performances continuing until 1912. There arrived the singularly beautiful film of "The Durbar of Delhi," which was the rage of London. In Paris it was shown at the Salle Peletier, where it was an equal success.

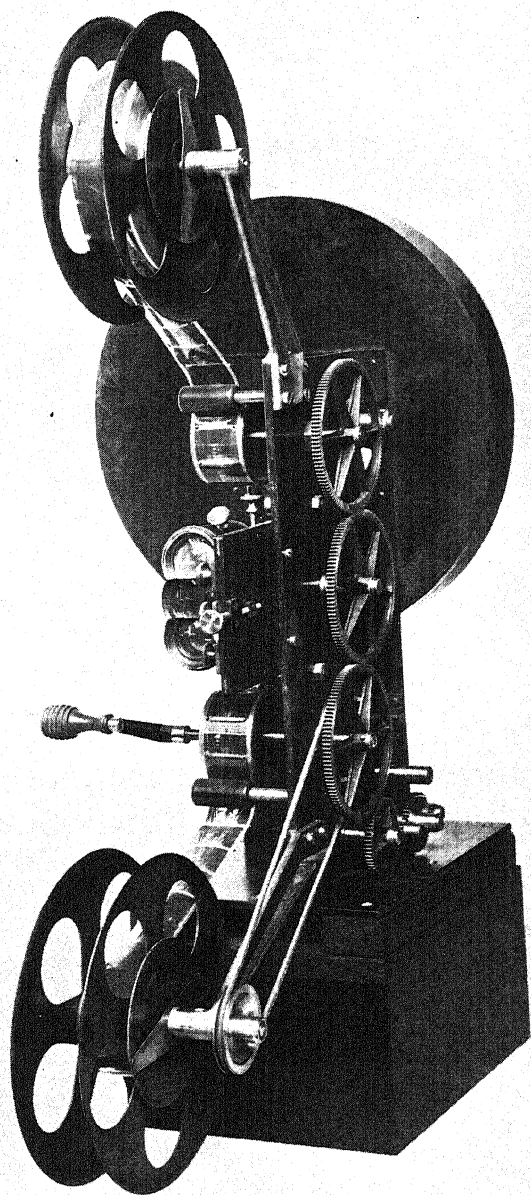
For some reason Kinemacolor of America failed to commercialize the process in the United States, and afterwards prolonged litigation ensued apparently between Kinemacolor and the rival group surrounding W. Friese-Greene.

We might note, in passing, that almost all these pioneers were living in Brighton and that they were all in their individualistic and several ways certain that they, and they alone, had inventions worth a fortune. Why did they not collaborate? Were they mutually acquainted? We shall probably never know.

The defects of the additive method were soon obvious to all; the audience suffered from excessive eyestrain, a phenomenon always associated with colour admixture by persistence of vision if the recurrence is only just above the flicker limit of sixteen alternations of the quality of the stimulus per second. The projection speed of 32 pictures per second used for Kinemacolor necessitated a special projector and the life of the film was short.

To obviate these defects, C. N. Bennett, F.R.P.S., proposed to take the pictures (C. Beck and Bennett, B.P. 1,642, 1911, and B.P. 24,159, 1912) two at a time through two vertically disposed sawn-off objectives. This idea had been suggested for three lenses by C. P. Christensen in B.P. 7,514, 1908, and by Otto Pfenninger in B.P. 25,908, 1906. Bennett also would project through two lenses (B.P. 1,900, 1912, and B.P. 10,639, 1912). And he describes a skipping printer in B.P. 26,173, 1912.

1908-35.—We must now go back for a moment to W. Friese-



(From an exhibit in the Science Museum, South Kensington)
FIG. 2.—Urban three-colour projector, 1900.

Blue-green
Red-orange



FIG. 3.—Two-colour "Kinemacolor" positive, 1911.
"The Durbar of Delhi."

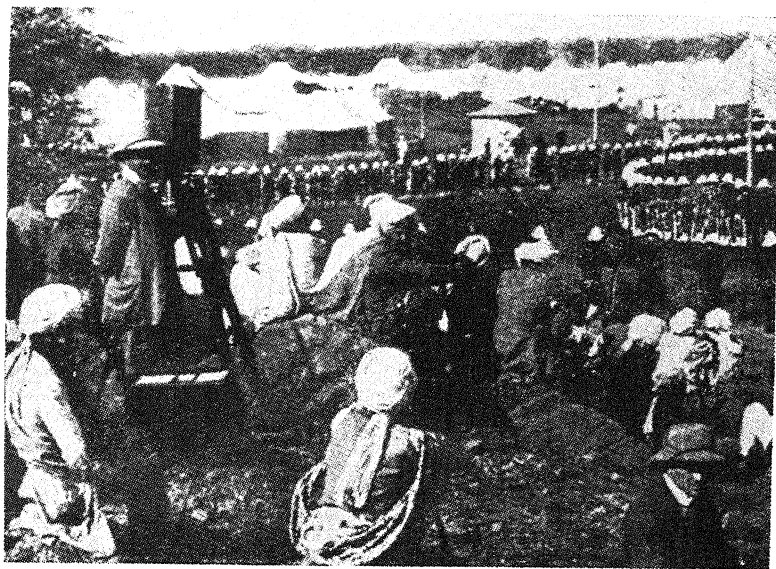
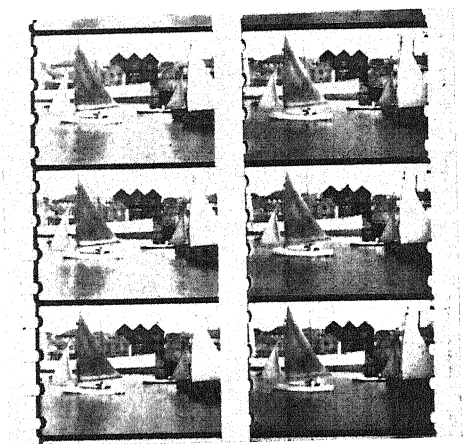


FIG. 3A.—Kinemacolor camera on location making the Urban-Smith
film, "The Durbar of Delhi," 1911.



Blue-green

Red-orange

FIG. 4.—Double-width film with central perforations, by Kodak. Used by Cinechrome Ltd. in 1921. Two-colour positive for additive projection.

Greene Patents Ltd. Through the courtesy of Mr. Samuel Cox, one of the pioneers of colour photography and colour cinematography, the following interesting facts have been obtained.

It appears that while G. A. Smith was working on Kinemacolor at Brighton, Friese-Greene had been experimenting on two-colour persistence of vision principles also, but instead of projecting through a rotating colour disc he stained each frame of a completed black-and-white print alternately red and green. The little staining machine with which he did this is still in Mr. Cox's collection in London. A film of Friese-Greene's was being exhibited at a theatre in Brighton, and a Mr. Lyons, who held certain Kinemacolor rights in Brighton, persuaded Kinemacolor to bring an action against the Friese-Greene theatre to prevent the showing of the picture. F. S. Edge, a well-known racing car expert, financed the Friese-Greene defence. Kinemacolor lost the action and appealed, winning their appeal. The case was then carried to the House of Lords, and the judgment reversed in favour of Friese-Greene. This litigation ruined Kinemacolor financially.

When Friese-Greene Patents Ltd. was formed in 1908, the negative was taken by exposure of 32 pictures per second successively through red and green filters (Kinemacolor used the same type of camera, which was made for G. A. Smith by Darling of Brighton). Finding that fringing was experienced, Colin Bennett made his proposals for a method whereby the two pictures were to be taken simultaneously through two lenses (sawn-off). Colin Bennett Ltd. was formed in 1911 to take over from Friese-Greene Patents Ltd. Sir William Hartley had assisted financially in the earlier company, and it was his finance which was behind the new company. Various defects were then discovered, and Cinechrome Ltd. was formed in 1914 as a reconstruction of Colin Bennett Ltd. Cinechrome Ltd. proceeded to develop the patents of F. Twyman, F.R.S. (of Adam Hilger Ltd.), J. S. Higham (son-in-law of Sir William Hartley), and H. Workman (B.P. 7,659, 1915; B.P. 13,042, 1915; Twyman's B.P. 18,611, 1915; and B.P. 16,810, 1915). Attempts were made in these patents to solve the parallax problems which had arisen in connection with Beck and Bennett's B.P. 24,159, 1912. The new Cinechrome beam-splitter had two lenses which were placed *behind* the prism divider, whereas Colin Bennett had tried to develop on the lines of division into two beams behind a *single* objective. Attempts were also made at this time to take three pictures, one beneath the other, on a single normal film. The pictures were spaced with two frames between each picture. An elaborate triple projector was also tried.

From this period until 1921 pictures were taken side by side, full-size, on double-width film, the film not only being perforated on the edges but also down the centre between the pairs of images. This film was made by Kodak (Fig. 4).

In 1921 Mr. S. J. Cox went to India to photograph the visit of the Duke of Windsor, then Prince of Wales. The pictures were taken on the wide film referred to. The film was exhibited at the Royal Society of Arts in 1922, a special projector with a wide gate being employed. It was later shown at the Stoll Picture Theatre, London. Mr. D. Daponte, one of the principal patentees of Cinecolor, exhibited in France for the benefit of the Red Cross, and the French Government were so impressed that they formed the Syndicat de Propagande Nationale par le Film en Couleurs Naturelles, with a list of presidents and vice-presidents of formidable dimensions.

The wide film was rejected in 1925, and a new beam-splitter adopted based on patents of D. Daponte and also of Adam Hilger Ltd. (see Beam-Splitter Cameras). The pictures were now turned sideways in pairs on 35-mm. film, each pair occupying the space of one frame. These pictures required a rather elaborate optical projection unit to erect the images. To exploit the new patent situation there was now formed, in 1929, Cinecolor Ltd. (After the decease of Sir William Hartley the business had been taken over by S. J. Cox and D. Daponte.) The financial backing for Cinecolor was supplied by Sir P. Malcolm Stewart (Chairman of British Portland Cement Manufacturers Ltd.). Subsequently, a holding company, Chromex Ltd. (incorporated in Canada), was formed, and Sir P. Malcolm Stewart and Cinecolor Ltd. vested in this company their full rights in the group of patents



FIG. 5.

covering this additive process. Dufay-Chromex Ltd. in 1937 merged the Cinecolor rights with the parent Dufaycolor interests.

Thus we see that this most highly developed of the additive processes relates back step by step to the founder of the motion picture, W. Friese-Greene.

1913.—Société Établissements Gaumont patented a triple-lens system (B.P. 3,220, 1912). Some pictures were projected in London (at the Coliseum?), but serious parallax was the cause of very noticeable fringing. "Gaumontcolor" was first shown in Paris, April 4, 1913, the programme including Bouquets of Flowers—Life in the Country—Trip to the Côte d'Azur—Carnival at Nice—Fashions—Majorca. In June it was shown in New York at the 39th St. Theatre, and actually included synchronized sound from gramophone records. Three

frames were recorded one above the other from three vertically superposed lenses. Each frame was 14 mm. high (3 perforations). The projection optical system was similar. Electrical remote control of registration was attempted.

By now most experimenters had realized that additive projection presented immense difficulties. Even as far back as 1906 E. J. Wall had said: "However idealistic the suggestion is, this is what we want—a length of cinematograph film, each picture in which shall be a record of the movement at the instant of exposure and at the same time in itself a complete colour record." Wall himself experimented with a dichromated gelatine process in 1911, but without much success.

The first suggestion of double-coated film for two-colour subtractive printing is by E. Lewy (D.R.P. 238,514, 1910), but nothing was done commercially until A. Hernandez-Mejia announced the details of his process from the United States (U.S.P. 1,174,144, 1913) (see *Brit. Journ. Phot.*, 1912, 59, 805). He called his process "Cinecolor-graph." "The amount of emulsion on both sides of the film is no greater than the amount now used on one side only" (see *New Moving Pictures*, 12, October 5, 1912).

This was followed by two-colour processes by Ives, W. van D. Kelley, William Francis Fox, and John E. Thornton.

The bipack method of obtaining two-colour negatives is traceable again to Ducos du Hauron (F.P. 250,862, 1895) and A. Gurtner (B.P. 7,924, 1903). One of the first to apply the bipack system to cinematography seems to have been P. D. Brewster (B.P. 2,465, 1915, and U.S.P. 1,222,925, 1917). He was also the first to use registering pins in cameras and projectors (U.S.P. 1,359,024, 1920).

C. H. Friese-Greene experimented with a two-colour additive process (B.P. 233,129) (*Phot. Journ.*, 1924, 64, 397). A colour disc was used in the camera carrying a red filter only, the alternative frame being exposed without a filter (suggested previously by Kelley). Contact positives were printed and stained successively red and blue-green. Projection was at normal speed. Visual fatigue due to colour bombardment was excessive. The process was based upon the patents of C. H. Friese-Greene's father, the pioneer W. Friese-Greene. A company called Colour Photography Ltd. was formed (B.P. 4,774, 1912).

1915.—The original "Kodachrome" process was the invention of J. G. Capstaff of Kodak Research Laboratories (B.P. 13,429, 1915). The negatives were taken by a beam-splitter camera. Positive prints were made, and from these negative images were printed in register on double-coated film. The images were bleached, the bath hardening the films only in the parts where the image had been. The two sides were then dyed in the usual two colours, namely red-orange and blue-green, the dyes entering the emulsion only in the unhardened areas, thus giving positive images. The silver was finally entirely removed.

1915-48.—At this period the name "Technicolor" first appears. The Technicolor Motion Picture Corporation had its origin in a firm of Boston engineers: Dr. Herbert Kalmus, Daniel Frost Comstock, and W. B. Westcott. Apparently they were assisted by E. J. Wall, F.R.P.S., in their early work. They began by attempting a two-colour additive process based on the patents of Westcott and Comstock, (U.S.P. 1,231,710). Comstock patented a prism divider behind the objective. Two images were obtained with two unexposed frames between them. The film was pulled down two pictures at a time. The film was projected by means of a special lens, registration being effected by two movable plane parallel plates between the film and the projection lenses.

The first film made by this additive process was "The Gulf Between," with Grace Darmond and Niles Welch playing the leads (1917). The manifold troubles of additive projection were soon discovered. Dr. Kalmus has said: "I concluded that the operator would have to be a cross between an acrobat and a professor." At this period, the Technicolor laboratory was housed in a railroad car, which contained complete processing equipment (Fig. 6).

William Travers Jerome, the well-known American lawyer, assisted with finance in the early stages (1920). The additive method was then abandoned. Prints were made from the negatives taken by the above-described beam-splitter. A skipping contact step-by-step printer separated the two components and thus two continuous positive prints were extracted from the negative bearing the alternate two-colour separations. The positives were now developed in a tanning developer and reliefs formed. The two reliefs were dyed and finally the two films bearing the dyed reliefs were cemented together back to back (B.P. 209,404, 1923). This idea had been suggested earlier by A. R. Lawshe (B.P. 131,319, 1916).

A small laboratory or pilot plant was built in the basement of the building occupied by the Technicolor engineers, Kalmus, Comstock & Westcott Inc., on Brookline Avenue, Boston, Mass (1919). The first Technicolor subtractive film was "The Toll of the Sea," supervised by Mr. Joseph Schenck; Chester Franklin, director; Anna May Wong, lead; and J. A. Ball, cameraman, later the outstanding creative engineer of Technicolor. This film was first shown at the Rialto Theatre, New York, November 26, 1922. The picture grossed more than \$250,000, of which Technicolor received \$150,000. The cemented prints cost 27 cents per foot! Another plant was built in Boston and a small laboratory in Hollywood. Technicolor and Famous Players Lasky Corporation next made "The Wanderer of the Wasteland." Prints were supplied at 15 cents per foot. Both pictures were exteriors. First artificial light photography was carried out in "Cytheria" (1924). In the fall of the same year Metro-Goldwyn-Mayer made "Ben Hur."

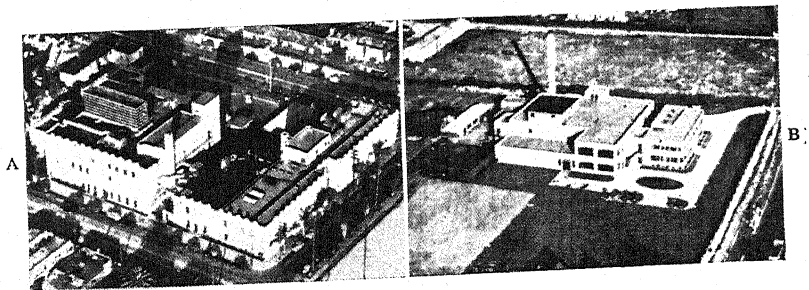
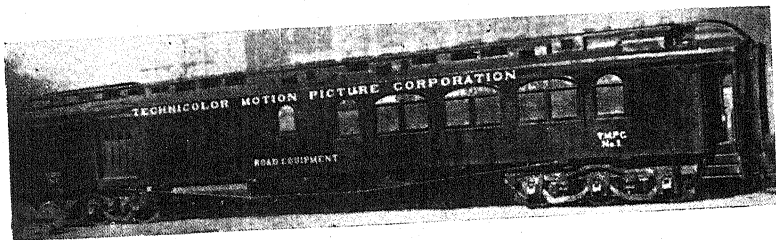


FIG. 6.—Technicolor Laboratories.
 A. In Hollywood.
 B. In England.
Above: Railway car laboratory, 1917.

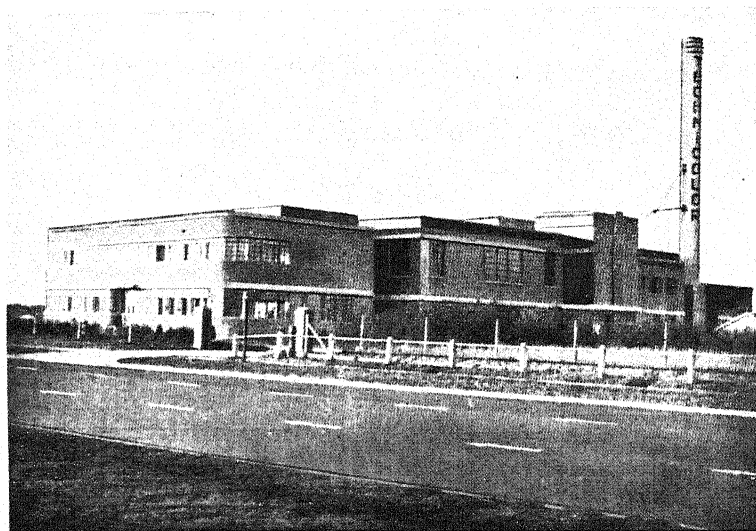


FIG. 7.—Technicolor Laboratories, Bath Road,
Harmondsworth, West Drayton, Middlesex. (See p. 16.)

"The Black Pirate" was made. This film was produced by Douglas Fairbanks in 1925, and at that date it was the best two-colour film which had been so far made.

Dr. Kalmus has said: "So far as audience reaction, Press reviews, and box-office were concerned it was a triumph from the start, but for the Technicolor Company it was a terrible headache." Prior to 1926, more than \$2,500,000 had been spent without very encouraging financial results.

In 1926 Technicolor went into production and made a number of shorts, distributed by Metro. Of these Dr. Kalmus remarks: "In my opinion Technicolor would not have survived without the experience of this series of short subjects" [6].

Technicolor made their last silent feature in 1929, "The Viking." It cost \$350,000. Metro reimbursed its cost.

In 1928 the printing method was changed to an imbibition process (B.P. 307,659, 1928), as great trouble had been experienced from curling of the film in the projector, which gave rise to focus variation. The imbibition process was successfully working in 1929 (U.S.P. 1,919,673). During this and the following year the following films were made: "On with the Show," the first all-talking Technicolor feature, "The Gold-Diggers of Broadway," "The Mystery of the Wax Museum," and many short films. Though these were admirable two-colour films, the audiences complained of lack of definition and consequent eyestrain.

In November 1929 Dr. Kalmus was reported as coming to London to discuss construction of a processing plant. At this date the *Daily Film Renter* of London commented: "Strange that Mr. Maurice Elvey is at present in New York negotiating with American companies to effect a deal in Raycol" (see page 265). At the same date Mr. Kay Harrison of Gerrard Industries Limited claimed that Cinecolor (see page 271) was "the only process of purely British origin which had been developed." This was the Mr. Harrison who was subsequently to become the managing director of Technicolor Ltd. Cinecolor Ltd. had been registered in August 1929, with a nominal capital of £1,050. However, the Technicolor laboratory had to wait until 1935.

In December 1929 Dr. Kalmus said that there were then thirty-four Technicolor cameras in Hollywood and fourteen features in production. He said that in 1928 the U.S. plant had a capacity of 12,000,000 ft. per annum. For the coming year contracts required 100,000,000 ft. for the U.S. alone. Perhaps with an eye on Cinecolor (British), he announced: "You can be assured positively of the ineffectiveness of any additive process to get anywhere ever." He estimated that the British plant would cost £100,000 and is recorded to have said: "We have been perfecting our process for twelve years, and I can say that the only future for colour lies in a process which can comply with these requirements:

COLOUR CINEMATOGRAPHY

1. It must not require very much more light in the studio or in projection than ordinary monochrome. Technicolor in projection actually requires less.
2. It must not require special projection equipment or modification of existing projection machines.
3. It must be capable of a three-colour process.
4. It must be reasonably cheap."

He concluded by telling the Press that Technicolor owned eighty world patents and that the capital approached twenty-five million dollars.

In 1930 the Warners said that they were "going over 100 per cent. to Technicolor." They were to make "Song of the West," "Under a Texas Moon," "Hold Everything," and "Golden Dawn." On January 22, Kalmus said: "Within two years the black-and-white motion picture will be as out of date as the silent picture is today"—a prediction which was not to be realized. In February he said that the sixth Technicolor laboratory would cost a million dollars and that their net earnings for the year would be a million dollars. What a convenient sum this "million dollars" is to the film industry! For example, in February 1930 the *Daily Film Renter* said: "Fox is spending a million dollars on a laboratory being built at the Western Avenue Studios. It will be used exclusively for the Fox 'Nature Color Process.'" Poor Nature! Poor colour! Always a million dollars. It was also stated that the experimental work had cost a million dollars.

In March 1930 First National claimed that they were the first to make an all-talking exterior colour film, "Heart of the North." During the same month Mack Sennett claimed to have invented a new colour process. One is curious to know what that process was.

Technicolor now adopted a beam-splitter camera (B.P. 398,339, 1932) of the type in which two films are exposed in two gates at right-angles to each other, the beam from a single objective being split by the semi-reflecting diagonal of a prism cube, the reflecting face being placed at 45° to the axis of the beam. The prism block consists of two 45° prisms cemented together to form a cube. This idea probably originated in J. W. Bennetto's B.P. 28,920, 1897, known as the "Semi-dialyte" system. With such a camera three-colour negatives are obtained by exposing bipack in one gate and a single film in the other. The imbibition process was now changed to three printings, and later a fourth key printing in black was added. In spite of these advances, great difficulty was experienced in getting support from the industry. Ultimately Walt Disney adopted three-colour for his "Silly Symphonies," 1933, and the first film, "Flowers and Trees," was a great and immediate success. This was followed by "Santa's Work Shop" and the famous "Three Little Pigs."

The American financier John Hay Whitney became interested at this stage, and he formed a production company known as Pioneer Films exclusively for the making of films in Technicolor. A contract was signed between Technicolor and Pioneer Pictures Inc. on May 18, 1933, which provided for the production of eight pictures. Positive printing for 1933 was double that of 1932. The number of cameras was increased from three to seven. The first complete picture was a delightful little film called "La Cucaracha," 1935. The production of this film marked an important turning-point in the history of the colour film, as it was the first commercially successful three-colour picture. It was followed by a sequence introduced into the Twentieth Century-Fox film "The House of Rothschild," and by the closing sequence in the Cantor picture "Kid Millions." Later "Becky Sharp" was made by Pioneer Films, their first full-length three-colour film. This film created immense controversy in the film industry all over the world (London, July 11, 1935).

Of this film Sam Goldwyn remarked: "It contains the most marvellous colour I have ever seen, it may do a great deal to show whether or not films in the future are to be 100 per cent. colour." "Becky Sharp" was directed by Rouben Mamoulian, and the art director was Robert Edmund Jones, a well-known New York stage designer. It was first shown at Radio City Music Hall. The *Cinema* said: "The whole film world recognizes in 'Becky Sharp' exactly the same test for colour that 'The Jazz Singer' was for sound. Public reaction to this film will decide the future of the screen as colour or black and white." Today, in 1949, the controversy is by no means decided [12].

This year also saw the production of "Trail of the Lonesome Pine" and "Dancing Pirate."

In 1935 Dr. Kalmus announced a cross-licensing patent arrangement with Kodak, and forecast the possibility of soon adopting a multi-layer single original coloured master positive film for taking the picture, the feasibility of this being clearly indicated by the advent of the new Kodachrome process. Several years were to pass before this method was adopted. It cannot be said that so far results have been obtained which compare with Technicolor prints derived from beam-splitter negatives.

Leonard Smith, A.S.C., was the first director of photography to use Technicolor monopack on a major studio production—shooting the exteriors for MGM's "Lassie Come Home" in 1942, while the interiors were made on the usual three strip negative. Monopack was improved, and its speed increased, to the point that it was used entirely for both interiors and exteriors on the 20th Century-Fox production of "Thunderhead" in 1944; with Charles G. Clarke, A.S.C., as director of photography. For the past several years, monopack has been increasingly used on productions for all or part of the camera record [17].

In 1935 there was formed in England a company under the name of Technicolor Ltd. with a share capital of £320,000, owned equally by the American Technicolor Motion Picture Corporation. The capital was subscribed in England, the interested parties being London Film Productions Ltd., Gerrard Industries Ltd., and certain others, including the Prudential Assurance Company. The American parent concern acquired 50 per cent. of the stock, approximately, in return for the patent rights, secret processes, and so forth. A magnificent laboratory was built at Harmondsworth, Middlesex, and is now servicing all British productions in Technicolor and prints of American colour productions for British distribution (Fig. 7). The first Technicolor English feature was "Wings of the Morning." Other early productions were "The Divorce of Lady X," "The Drum," "Sixty Glorious Years" (produced by Herbert Wilcox), and "The Four Feathers" (a Korda film).

Between 1936 and 1939 other feature-length Technicolor productions were:

- "A Star is Born," Janet Gaynor and Frederic March (Selznick International Pictures) (1936).
- "Garden of Allah," Marlene Dietrich (Pioneer Pictures) (1936).
- "God's Country and the Woman" (Warner Bros.) (1936).
- "Ramona" (Twentieth Century-Fox Productions) (1936).
- "Ebb Tide" (Paramount) (1937).
- "Gold is Where You Find It" (Warner Bros.) (1937).
- "Goldwyn's Follies" (Samuel Goldwyn Pictures Inc.) (1937).
- "Her Jungle Love" (Paramount) (1937).
- "Nothing Sacred" (Selznick International Pictures) (1937).
- "Vogues of 1938" (Walter Wanger Productions) (1937).
- "Snow White and the Seven Dwarfs," Walt Disney (R.K.O. Pictures) (1937).
- "Tom Sawyer" (Selznick International Pictures) (1937).
- "Coronation Film" (1937).
- "Men with Wings" (Paramount) (1938).
- "Adventures of Robin Hood" (Warner Bros.) (1938).
- "Valley of the Giants" (1938).
- "Heart of the North" (1938).
- "Jesse James" (1938).
- "Kentucky" (1938).
- "Sweethearts" (1938).
- "Little Princess" (1938).
- "Wizard of Oz" (1938).
- "Dodge City" (1938).
- "Gone with the Wind" (1939).

The number of subsequent American productions runs into hundreds. British feature-length Technicolor films from 1937 to 1947 were:

- "Wings of the Morning" (New World) (1937).
- "Victoria the Great" (part colour only) (Imperator) (1937).
- "Claudius" (never completed) (Korda) (1937).
- "Pagliacci" (Trafalgar) (1937).
- "Divorce of Lady X" (Denham Films) (1938).
- "The Drum" (London Films) (1938).
- "Sixty Glorious Years" (Imperator) (1938).
- "The Mikado" (G. & S.) (1939).
- "Four Feathers" (London Films) (1939).

- "Over the Moon" (London Films) (1939).
- "Sons of the Sea" (British Consolidated) (1940).
- "Thief of Bagdad" (Korda) (1941).
- "The Great Mr. Handel" (G.H.W.) (1942).
- "Queen Victoria" (composite reissue) (Imperator) (1942).
- "The Life and Death of Colonel Blimp" (Archers) (1943).
- "This Happy Breed" (Two Cities) (1943).
- "King Henry V" (1943).
- "Western Approaches" (1943).
- "Blithe Spirit" (1944).
- "Cæsar and Cleopatra" (1945).
- "Men of Two Worlds" (1946).
- "London Town" (1946).
- "A Matter of Life and Death" (1946).
- "Laughing Lady" (1946).
- "The Man Within" (1947).
- "Black Narcissus" (1947).
- "Bonnie Prince Charlie" (1947).
- "Son of Lapland" (1947).
- "Red Shoes" (1947).
- "Scott of the Antarctic" (1947).
- "Saraband for Dead Lovers" (1947).
- "An Ideal Husband" (1947).
- "Blanche Fury" (1947).
- "Jassy" (1947).
- "XIVth Olympiad—The Glory of Sport" (1948).

Technicolor delivered the enormous total of 165,027,297 feet of positive colour prints in 1946, covering 33 American and 5 British productions in addition to many cartoons and short subjects. During 1947 this figure was surpassed and the capacity has now been increased to handle 300,000,000 ft. per annum.¹

1910-34.—One of the outstanding figures of this period was William van Doren Kelley (1876-1934). In 1913 he formed a company called Panchromotion for the development of an additive colour process somewhat similar to Kinemacolor. In order to minimize colour fringing he increased the number of pictures taken per second. He attempted three-colour additive projection by successive projection. During this period a double-coated stock and a bleach formula, which had much to do with the later Prizma process, were perfected. Somewhat later Prizma Inc. was formed, with sufficient capital to undertake regular production. The first Prizma film was "Our Navy," released in 1917 at the 44th Street Theatre, New York City. The colour was produced by an additive process using a colour disc on the projector.

Kelley was not satisfied with the additive system and believed that colour could be applied directly to the film. In order to carry out this idea he entered into partnership with Carroll H. Dunning and Wilson Salisbury, and a laboratory was opened at 205, West 40th Street under the name of "Kescadacolor." Their first film made by the subtractive process was a picture of the American flag. In a length of 50 ft. it was shown at the Roxy and Rialto, New York, on Septem-

¹ In 1940 the output was approximately 80,000,000 feet. In 1941 it was 97,014,757 feet, and the profit was \$942,912, or one dollar per hundred-foot run.

ber 12, 1918. Shortly after the success of this showing, Kelley returned to the Prizma Company, which was reorganized. Longer films were undertaken, and in 1919 a single-reel travel subject was subtractively coloured. J. Stuart Blackton of Vitagraph saw this picture and was so impressed that he decided to make a feature-length picture in Prizma. "The Glorious Adventure" was made at the Stoll Studios, Cricklewood, London, with Lady Diana Manners in the principal part. Some £150,000 was spent on this production and "The Virgin Queen," without much success being obtained. The negative seems to have been sent to America for processing. Prizma charged 25 cents a foot for prints.

In 1919 Kelley produced a series of coloured cartoons which were drawn by Pinto Colvig. In 1924 he introduced "Kelleycolor," which was an imbibition process. Two colours were imbibed on a black-and-white key image. In 1926 he became associated with Max Hand-scheigl in the formation of the Kelleycolor Company, which was bought by Harriscolor in 1928. In 1929 Kelley started experimenting with bipack, and at the end of his life he was experimenting with methods for cementing bipack emulsion to emulsion.

Kelley was an interesting and important figure in the early days of colour cinematography. He combined the work of Friese-Greene, Hernandez-Mejia, and others. Prizma patent rights were subsequently acquired by Magnacolor, which was operated by Consolidated Film Industries Inc. At one time it was also stated that Vitacolor had taken over the Prizma patent rights. Today Consolidated Film Industries is using Trucolor,¹ whose sponsors can therefore claim an unbroken descent from Kelly.

1922.—The late Aron Hamburger, an American chemist who resided in England, patented a dye-toning process which ultimately became known as the "Polychromide" process (E.P. 203,358, 1922). The negatives were taken in a beam-splitter camera which in many respects anticipated the Technicolor camera. The positive film was double coated. A very lightly exposed and developed print was dyed by a coating machine with mixtures of basic dyes. On one side the film was dyed with magenta and auramine mixed, and on the other with malachite green and a basic blue mixed. The film entered a chromic acid mordanting bath *subsequent* to dyeing, which was an interesting innovation. Later an iodide mordanting bath² was used in place of chromic acid. The process was commercially worked in London for many years, the plant and machinery being eventually dispersed and sold in 1937.

1920-9.—T. A. Mills was the inventor of a process known as "Zoe-chrome" (B.P. 172,714, 1920). One full frame was succeeded by three small pictures occupying the space of a normal frame. All four pictures were exposed at the same time. The three small pictures were exposed

¹ B.P. 626,979.

² The formula was worked out by the writer in 1934.

through tricolour filters, while the large picture was a normal panchromatic record. The black-and-white negative was taken with an $f/3.5$, 3-in. lens, while the small negatives were made with three lenses of about $f/4.0$ and of shorter focus, bunched together to reduce parallax, and placed immediately below the main lens. All four lenses were mounted together for focusing. In printing, the alternate full images of the negative were printed in succession; the positive was developed as usual, varnished, and then *recoated with emulsion*. One of the small images was printed by enlargement in register with the full-sized image, developed, and dye-toned. The film was again varnished and recoated with emulsion, and the cycle of operations was repeated for the two remaining colours. This process is no longer being worked commercially.

1928-35.—A company was formed in England to exploit an additive process known as "Raycol." In July 1929 Maurice Elvey announced demonstrations of the process at studios and laboratories at 10, Great Earl Street, London. He quoted patent agent's report and counsel's opinion as to the novelty of patent applications. In September, six films in Raycol to be made by British International were announced. Nothing was done, however. A subsidiary called Talking and Sound Films Ltd. was formed, but the scheme was dropped, as Elvey said a sufficient number of production companies were already in negotiation. In 1930 Elvey said that he would make "seven features, including the life of Shakespeare." Alas! a great deal of money was invested by the public, but comparatively little progress was made towards adequate commercialization. In 1933 "The Skipper of the *Osprey*," by W. W. Jacobs, was filmed in London by the Raycol camera. Additive projection was required, and when the film was distributed all the practical difficulties of this method soon stood revealed. Mechanics had to follow the film about in order to ensure that the projection lens was correctly adjusted, and telegrams were often received by the distributors informing them that the projectionist could not get the pictures into registration. However, when perfectly projected, much of the colour of "The Skipper of the *Osprey*" was comparable to anything which had been shown up to that date. In 1933 the writer assisted the Raycol British Corporation in the design of an anti-parallax prism objective system. Up to that time the Raycol optical system had exhibited serious parallax errors (E.P. 398,100, 1933).

The Raycol British Corporation was wound up some years ago, thus supporting Dr. Kalmus's views on additive processes, which nevertheless periodically reappear with almost tidal frequency. In this region confidence tricksters abound.

1909-35.—R. Berthon was the original patentee of an important invention now called the "lenticular" process (B.P. 10,611, 1909). In association with A. Keller-Dorian (B.P. 24,698, 1914), methods

were patented for embossing films with cylindrical, or other type, refracting elements. This process was exhibited in Paris in 1923, being then known as the Keller-Dorian-Berthon process. The method was successfully commercialized for 16-mm. film by Eastman Kodak in 1928 under the name "Kodacolor," the rights having been purchased in 1925.

In England a great deal of public money was invested in the Berthon-Keller-Dorian patents; but problems of copying ultimately prevented any practical application of the lenticular process to the commercial motion picture. In America the Keller-Dorian Color Film Corporation experimented for some years without solving the probably insurmountable optical problems. Lenticular film is an outstanding instance of a method which at the beginning was capable of providing results of an attractive nature, but which nevertheless contained certain inherent weaknesses which its promoters refused to recognize. It is said that at least ten million francs have been expended upon research in France, about £250,000 was invested in England, and a very large sum has been spent in the United States. Other modifications of the lenticular process were for a time exploited by the Kislyn Corporation in America, and by various companies in France and Germany (see description of Agfacolor lenticular film, page 321).

1925-35.—Originating in the Dufay "Diophtochrome" plate, the Dufaycolor mosaic film has so far been the only successful attempt to apply the micro-colour-screen method to motion picture film. The Diophtochrome plate was made under the patents of Louis Dufay, a French photographer, and his screen plates were on the market from 1910 to 1917. From 1925 onwards a very large number of patents were granted for various aspects of what was then known as the Spicer-Dufay¹ process. A great deal of money was spent by Spicers Ltd., the well-known paper manufacturers, on perfecting this process. The technical work in England was under the supervision of T. Thorne Baker, F.R.P.S., who with Louis Dufay and Charles Bonamico had carried out all the earlier research previous to the Spicer period. Baker has recounted that several thousand feet of negative were made in the south of France on 8-line (per mm.) *réseau*, and prints from these were shown at the Pavilion Theatre, London, in 1928, but the loss of resolving power must have been excessive.

In 1937 the various interests of the Spicers, Ilford, and others were merged with the interests of Sir Malcolm Stewart, Mr. D. Daponte,

¹ Spicer-Dufay Ltd. was incorporated in 1932, and the name was changed to Dufaycolor Ltd. in 1933, the capital being £288,000 in £1 shares. The capital was increased in 1933 to £630,000. R. E. Lambton and Spicers Ltd. assigned rights to Dufaycolor Ltd., and an interest in the Spicer-Dufay patents was assigned to Colortone Holdings Ltd. In 1934 F. S. Cotton was managing director, and a director of Ilford Ltd. (the late Major Mein) was on the Board. Colortone Holdings and Cotton held between them a controlling interest.

and others in the Cinecolor process (not to be confused with the American process), and a large public company was formed under the name of Dufay-Chromex Ltd. Prior to 1939 the United States market was handled by Dufaycolor Company Inc. This company has since ceased to operate, largely owing to the poor exploitation of the motion picture possibilities in America.

In 1931 the first satisfactory films were exhibited in England, but at this period the problem of copying the original film (a coloured reversed positive) had not been satisfactorily solved. In 1934 Ilford Ltd. acquired the control of the British Empire rights, and during this year they placed on the market 16-mm. film which received an enthusiastic welcome from amateur cinematographers. During 1934 a certain amount of work was produced in the studios, notably a sequence in a film called "Radio Parade," a British International Pictures production. The film was directed by Arthur Woods and made at the B.I.P. Studios, Elstree. Claude Friese-Greene was cameraman. This film was photographed on reversal Dufaycolor, and the prints were also reversal positives. It was trade shown on December 12, 1934, at the Regal, Marble Arch. The original appearance of Dufaycolor was disappointing. During 1935 British Movietone News exhibited some Dufaycolor news pictures of the Jubilee processions, which necessitated printing a large number of copies very rapidly. These prints were reversal copies and they suffered from a granular effect known as "boiling." The work at this period was carried out by Kay's Laboratories Ltd. of London.

The invention by Dr. D. A. Spencer, F.R.P.S., in 1936, of the *depth developer* made negative-positive processing practicable, since the restriction of development to the layer of emulsion in immediate contact with the *réseau* reduced spreading of the image with its consequent desaturation; also irradiation was reduced to a minimum. Furthermore, the work of Dr. G. B. Harrison and Mr. R. G. Horner of Ilford Ltd. led to great improvements in the illumination system of contact printing machines, moiré patterns being completely eliminated.

The improvements resulting from this research work were first put to a practical test in the Coronation film, which was produced by Dufay-Chromex Ltd. and distributed by Pathé Pictures Ltd. The processing work on this occasion was carried out by Ilford Ltd. at their laboratories at Brentwood, Essex.

Negative-positive printing of Dufaycolor film was a success, and the beauty of the Coronation film made a great impression both on the film industry and on the public. During 1937 and 1938 a large number of shorts were made in England and on the Continent, while in the U.S. an admirable record was made of the great yacht race which was released under the title "Sails and Sailors." Among other pictures made during this period the following should be mentioned:

"Trooping the Colour" (Pathé), "Royal Naval Review" (Pathé), "St. Moritz" (Rayant Pictures), "Farewell Topsails" (Dufay-Chromex). Studio pictures such as "Old Soldiers Never Die" (Greatarex-Pearson) and "Souvenirs" proved that Dufaycolor could equal any process in definition and accuracy of colour reproduction.

In 1937 Dufay-Chromex Ltd. established a processing laboratory at Thames Ditton, Surrey. Special Dufaycolor printing machines were designed and constructed by W. Vinten Ltd., the Lawley Apparatus Company, and by André Debré of Paris.

Processing laboratories are today equipped to print Dufaycolor in Paris, Geneva, Rome, Johannesburg, Bombay, and Barcelona. In 1938 a modified *réseau* considerably extended the range of hue reproduction, and an emulsion was perfected for photography by tungsten filament lamp illumination. The world requirements of *réseau* are at present entirely supplied by the company's factory at Sawston, Cambridgeshire. The precision machinery for ruling the microscopic lines on the film base is chiefly the work of the French engineer Charles Bonamico.

It is likely that a still finer screen will shortly be available; the high resolving power which will then be obtained, combined with the very beautiful colour reproduction for which the process has become famous, will ensure a continued life for this make of colour film for some years to come.

1930-35.—At this date, in America, processes being worked commercially were: Multicolor, Sennett Color, Harriscolor, Vitacolor, Magnacolor, Fox Color, and other processes which we refer to later. Multicolor had installed an elaborate and costly plant in Hollywood, but by 1933 this process was no longer being worked.¹

From 1928 onwards there appeared a very large number of two-colour processes, both additive and subtractive. No further advance of historical importance was made until Gasparcolor film appeared in 1934. For the first time a triple-layer coloured-emulsion positive material was made which could be printed and processed with quite minor modifications of contemporary laboratory technique, and by which a full three-colour continuous tone image could be obtained without resort to chemical toning, colour development, or the use of dyes in processing. This first successful application of the bleach-out type of process was achieved by Dr. Bela Gaspar, a Hungarian chemist, who spent several years in research work before satisfactory prints were exhibited. Given normal three-colour separation negatives, Gasparcolor film is capable of yielding extremely beautiful prints. The process was first worked in Germany.

In 1934 Gasparcolor Ltd. was formed in Great Britain. This company made many successful advertising films, but lack of a beam-

¹ Multicolor was the direct ancestor of the Cinecolor process of today.

splitter camera prevented the use of the process for entertainment films. Films printed on this material were shown to the Royal Photographic Society in February 1935 to illustrate a paper read by the writer. A paper was also presented and films shown at the Proceedings of the International Congress of Photography in Paris (July 1935). The film was manufactured by Gevaert in Belgium, but the war put an end to the operations of the British company. Dr. Gaspar and his associates emigrated to Hollywood, where they formed an American company. Exploitation of Gasparcolor motion picture film in its original form has ceased, but a modified negative-positive process will in all probability ultimately emerge [11].

1935.—“Kodachrome” was adopted for the second time by Kodak as a name for a colour process developed in the research laboratories at Rochester, U.S., from the monopack patents of Leopold Mannes and Leo Godowsky. Both men were anticipated by earlier inventors such as H. Kuhn (B.P. 6,921/91), K. Schinzel (*Brit. Journ. Phot.*, 1905, 52, p. 608), and F. Sforza (*Brit. Journ. Phot.*, 1910, 57), and Dr. L. T. Troland of Technicolor (U.S. Reissue 18,680; B.P. 370,908, 382,320). These were the inventors of “monopack,” while colour development is traceable to Rudolph Fischer, father of multilayer colour-coupler development (B.P. 15,055, 1912; and B.P. 2,562, 1913) [9].

In England a first exhibition was given at Kodak House, London, on April 5, 1935, and films were exhibited at the Ninth International Congress of Photography in Paris (July 1935). Kodachrome film was made available to amateurs in the form of 16-mm. film in the spring of 1935 in the United States. In England it was marketed first in 1936. The old lenticular Kodacolor process was withdrawn from production.

In 1940 the earlier processing procedure was altered from a controlled diffusion principle to differential re-exposure with coloured light, much simplifying the process.

The use of 35-mm. Kodachrome for motion pictures has hitherto been used only by Technicolor; 16-mm. Kodachrome is, however, generally available, and it is being increasingly used as the original record for Technicolor films.¹ It has also been used by Gasparcolor Inc. and Cinecolor Corp. [13]. It cannot, however, be said that prints made from separation negatives from Kodachrome can equal the delicacy and accuracy of colour obtainable from those derived from separation negatives made from the original subject [7].

Kodachrome film has been an enormous success. Its subtractive primaries are of high saturation, and published absorption curves, particularly of the cyan and magenta, indicate particularly suitable

¹ The first feature-film to be photographed entirely by monopack in the United States was “Thunderland—Son of Flicka,” a Twentieth Century-Fox production, in 1945-6. It was printed by Technicolor; the monopack was, probably, 35-mm. Kodachrome. Monopack was used for the first time in M.G.M.’s “Lassie Come Home.”

characteristics. The colours are reasonably stable. Eastman say: "We believe, but do not guarantee, that a life of many years can be expected for pictures made on present Kodachrome film, providing reasonable precautions are taken."

In 1942 Eastman introduced a new monopack three-colour *negative* film under the resuscitated name "Kodacolor," formerly applied to the lenticular process. Kodacolor appears to be based on the patents of M. Martinez (U.S.P. 2,269,158; B.P. 505,834), proposing the use of a coupler dissolved in a resin which is then dispersed in the emulsion. Martinez was followed by Eastman, Barnet, Du Pont, and Ilford. The notion of a water-permeable binder so that colour couplers will not diffuse is merely one solution of the general problem of diffusion which was solved in Agfacolor by attaching long-chain molecules to the coupler.

Presumably Kodacolor film could also be used as a positive film, and there would appear to be no reason why this process should not provide a negative-positive material equal in quality with Agfacolor or Ansco Color. Developments on these lines may be expected. Up-to-date Kodacolor film has been made available only in the form of roll-film.

Kodacolor film was the first monopack material to incorporate an emulsion layer giving a neutral grey masking image [8].

1937-9.—Agfacolor 16-mm. integral tripack film (reversal process) provided a welcome addition to the colour films then available in the sub-standard field. The emulsion layers incorporated non-diffusing colour couplers of the type now familiar to us and a yellow filter of colloidal silver was sandwiched between the uppermost blue sensitive and the middle green sensitized emulsion layers. The period was remarkable for patent activity in the integral tripack and lenticular embossed film regions. Eighty or more patents covered a concentrated German attack on the perennial problem of copying lenticular film. Dr. Bela Gaspar was also active with about thirty new patents covering, mainly, proposals for integral tripack negative film, methods of copying, and colour-development chemistry. I.G. Farbenindustrie covered various aspects of the chemistry of non-diffusing colour couplers and of processing film embodying these. Eastman filed over forty new patents dealing with similar monopack problems.

At this period three processes shared the bulk of the world's demand for professional motion-picture 35-mm. colour film—Technicolor, Dufaycolor and Gasparcolor. The first process was predominant. Dufaycolor achieved considerable success in Britain but was unable to compete seriously with Technicolor owing to an inherent weakness, the inability to make duplicate negatives of the requisite quality.

Optimistic inventors contributed still further optical combinations for beam-splitting, but the perfect functioning of a prism is not made more likely by the multiplication of its parts. There was Hudeley's (B.P. 444,051). This prism belongs to Classification 3E (see page 541),

there being three objectives behind a prism system and three sub-standard pictures in the space of one normal frame. A further patent on the Brewster camera is B.P. 450,673. Two-colour beam-splitters reminiscent of Raycol re-emerge in Thomas and Bryan's B.P. 453,221. One would have thought it late in history for this species of two-colour additive process. The very complex prism described in Bellingham and Stanley's B.P. 459,664 was designed in accordance with the writer's requirements, for Gasparcolor, in 1935. A certain amount of practical work was accomplished, but it was found extremely difficult to retain perfect registration of the enlarged sub-standard negatives, even though the originals were quite free from parallax errors. This prism is used in conjunction with Bellingham and Stanley's B.P. 451,274, which covers an ingenious arrangement of the three sub-standard frames spread over two normal frames. A. H. Kamfer proposed to take (B.P. 469,359) and project (B.P. 478,766) four colour sub-standard records in successively exposed pairs. L. Klaver described a four element prism cemented cube giving images on three films, the divider being behind the objective (B.P. 472,468). The writer patented a similar beam-splitter in B.P. 475,415, with colour filters introduced within the block, "so that any stray light reflected from a portion of the prism lying beyond the reflecting plane responsible for the formation of a lateral image will, when finally emerging from the face of the prism adjacent to the plane in which the said image is to be recorded, be minus light which the recording filter is capable of transmitting, or, if a photographic emulsion is used, which does require such a filter, which the emulsion is capable of recording."

W. H. and E. C. Harrison described a two-colour beam-splitter in B.P. 473,782. The arrangement shows a semi-transparent mirror and a prism in front of a pair of sawn-off objectives providing the usual two sub-standard negatives within the area of one normal frame. Further Hillman patents were B.P. 478,500, 478,501, the latter dealing with additive three-colour projection: later he turned his attention to three-colour beam-splitters of considerable complexity, B.P. 483,817, 483,819, 483,820, 494,333, 494,334. L. Horst would take (B.P. 485,190) three-colour records side by side across the film, surely an unnecessarily difficult procedure. Pairs of colour-record images arranged side by side and side uppermost are provided by a complex beam-splitter patented by Cosmocolor Corporation, B.P. 489,333 and 474,800. The arrangement on the film is the same as the Busch process (see page 268). Cosmocolor was a two-colour subtractive process of normal type, using for the print a double-coated positive stock. Presumably the sub-standard records were enlarged by an optical printer and the images toned by a variant of the organic or inorganic toning methods. It is reported as being the invention of Otto C. Gilmore.¹

¹ See also B.P. 556,426 of the Cosmocolor Corporation.

1945-49.—When the Allied photographic service experts entered the Agfa factory at Wolfen they found no outstanding improvement on the pre-war Agfacolor 16-mm. reversal film. They found, however, that the Germans had successfully made both negative and positive motion picture monopack films, the chemistry of manufacture being almost identical to the reversal product [10]. Feature films had been made by UFA, and it transpired that prints had been made in Paris and Prague and perhaps elsewhere. The Germans installed a processing machine at the State Laboratory in Prague, presumably to be relatively safe from bombing. Some thirteen feature pictures and a number of shorts were made and Europe got quite used to Agfacolor. The Allied intelligence authorities circulated the full manufacturing data to all photographic manufacturers, most of whom are probably now engaged in the task of reproducing Agfacolor film. It will not prove a simple task. Of interest is the fact that material made subsequent to the inclusion of the Agfa works in the Russian zone of occupation exhibits a marked improvement in colour range. A film recording the triumphant entry of the late Dr. Benes into Prague contains reds and flesh colours superior to those observed in the captured wartime German productions, in which the reds were marked by a brownish hue and the flesh lacked pinks. This is true also of films made by the Russians, such as "Sports Parade, Moscow," and "La Fleur de Pierre," the latter made at the Barrandor Studios in Prague. This advance is traceable to an improved magenta coupler. The ultimate result of the freedom from patent restraint now enjoyed by British and other manufacturers is difficult to forecast, but one can be fairly sure that the user will soon have quite a few makes of colour film of the tripack class from which to make his choice.

In the United States before the war Ansco Inc. (then Agfa-Ansco), a branch of General Aniline and Film Corporation, had naturally full access to the German technical data and the advantages of patent protection owned by the parent company, the sinister I.G. Farbenindustrie. Ansco had placed an American-made Agfacolor on the market before the United States entered the war. This was christened Ansco Color Film and issued as 16-mm. reversal film, 35-mm. cartridges, and cut film. General opinion was favourable to the new product, among other reasons owing to the general release of processing instructions; its principal competitor at the time could not follow this policy, owing to the complexity and difficulty of the Kodachrome processing procedure, which had until recently been reserved to the manufacturer.¹ In 1946 three types of 35-mm. Ansco Color reversal film for motion

¹ "Ektachrome," a reversal colour positive film, and "Ektacolor," a colour negative embodying integral colour masking, both products of Kodak, can be processed by the consumer. Similar materials will shortly be available for professional motion pictures, and they will be known as, respectively, EASTMAN COLOUR POSITIVE and EASTMAN COLOUR NEGATIVE. The former material, when used in conjunction with the colour negative, will of course not require reversal. (U.S. 2,453,661 and B.P. 586,211, etc.)

pictures were made available to American film producers, and full processing instructions published [14]. Negative and positive 35-mm. films for the motion picture industry will eventually be released, and it may be presumed that these materials will be practically identical to the latest German product. (B.P. 602,881, etc.)

Anso designed during the War automatic processing machinery for 16-mm. reversible film, and special 35-mm. machinery has been constructed. The processing of the reversible film needs very rigid control, and in general every precaution has to be taken to control temperatures and the chemical state of the baths.

In 1949 Du Pont announced a release colour positive film for professional use. This is known as Type 275. The product is intended for use in printing from three-colour separation negatives. The film has three light-sensitive layers, each sensitized differently so that the desired layer can be exposed by suitably filtered light. (B.P. 611,846-7.)

The light-sensitive silver halide grains in each layer are suspended in three synthetic polymer layers which combine the functions of carrier and colour generators. The polymer molecules have attached to them chemically the necessary colour-forming structure to produce the three subtractive primary colours: yellow, magenta and cyan.

The silver grains, when developed, are intimately in contact with the colour-forming groups. This results in very high efficiency of dye formation and the use of very thin layers for increased resolution.

The important magenta layer is on top, while the least important yellow layer is on the bottom. This contributes to sharpness of definition. (See U.S.P. 2,462,151; U.S.P. 2,414,208; B.P. 600,039-40, 619,553, etc.)

In the tripack multilayer solution of the problem of colour photography we have returned to one of the proposals of Ducos du Hauron, namely the "Polyfolium Chromodialytique," in which he had conceived an ideal multiple-layer emulsion in each stratum of which a different part of the spectrum could be recorded. Only rarely has such imaginative foresight been equalled in the history of applied science.

In 1948, Herbert J. Yates, president of Republic Pictures Corporation, of which Consolidated Film Industries is a division, announced the Trucolor process. In its present form, this process comprises a two-colour film, but the method, which takes advantage of manufacturing technique perfected in producing products such as Ektachrome and Ansco Color film, is novel. The film support is coated on both sides with single layers of emulsion containing non-diffusing resin-protected colour couplers. The classical processing procedure for two-colour films is thus much simplified since metallic or dye toning is avoided. It is required only to print the two emulsions with the usual bi-pack negatives and to process the film in a suitable paraphenylene diamine formula. According to Yates, Eastman Kodak have accepted an order to manufacture twelve

million feet of Trucolor raw stock. It will be interesting to see whether a three-colour process is evolved from the present procedure. It has been reported that Arthur J. Miller, general manager of the Fort Lee plant of Consolidated, was the prime mover in the development of this colour-coupler process. There would appear to be no impediment to the exploitation of similar methods by European manufacturers in view of official publication of the manufacturing details of the Agfacolor non-diffusing colour-coupler containing emulsions. The application of such information to specific variations, for example, to double-coated emulsions on one or both sides of the support, can hardly be conceived to constitute patentable inventions [16].¹

A process being worked in Hollywood at the Trimble Laboratories is known as "Fullcolor." As far as can be determined a typical two-colour processing procedure is employed. Thus duplitzed Eastman Type 5509 stock is used—one side being toned a Prussian Blue and the other side dye-toned. The sound track is Prussian Blue. It seems therefore to parallel Cinecolor in technique. Master negatives are derived from 16-mm. Kodachrome or bipack. The plant capacity is claimed to be 35,000 ft. per day.

In France a process which has attracted some attention is known as "Chimicolor." This is a three-colour subtractive film printed from three-strip negatives exposed in a beam-splitter camera fundamentally similar to the Technicolor camera. Double-coated film is dyetoned by mordanting, one side magenta and the other side cyan. Subsequently the surface of one side is sensitized with bichromate and exposed to a positive. The exposed and therefore insolubilized gelatine rejects dye. This is strictly in accordance with the technique of the Pinatype process of Leon Didier (F.P. 337,054, 1903). The third printing is hence by differential absorption of a yellow dye applied to the re-coated surface. A protective varnish is applied to the finished product. Work dates back to 1931. The chief technical sponsor is R. Valette, who was a pupil of Didier. Didier was an associate of the great Ducos du Hauron, so that the process can boast a sound ancestry.

Still another French process is called "Thomson-color."² The original record is a lenticular film. Presumably the camera record is by reversal processed to a positive. From this positive three separation negatives are extracted by optical printing (see Lenticular Film). The print is then made on double-coated film. It is mordanted and dye-toned one side yellow, and the other side cyan. One side is subsequently re-coated with emulsion, and finally toned magenta with a nickel salt. Mention should be made of Kalichrome for which is claimed the production of two- and three-colour prints, using double-coated stock. The usual dye mordanting and re-coating with emulsion is employed

¹ In spite of the granting of B.P. 626,979.

² Compagnie Française pour l'Exploitation des Procédés Thomson-Houston.

to obtain the third colour by once again mordanting and dye-toning.

Much has been heard of the brothers Roux, who have recently obtained wide publicity for their additive system. It does not appear that any marked advances have been made on the optical system described in B.P. 385,141, 1932. The loss of light in projection is inevitably very serious, with the result that the inventors are said to be relinquishing their additive projection beam-registering lens in favour of a subtractive print made from the three, or four, sub-standard negatives in the area of a 35-mm. frame provided by the Roux beam-splitter optical unit. The negative arrangement is not dissimilar from that of Francita and Thomascolor. It is proposed to print optically by enlargement from each miniature negative direct to a 35-mm. colour positive monopack material, such as Agfacolor, Gevacolor. The chief difficulty would be to obtain perfect registration.

Cinecolor (American) now plays a much more important part in the colour film situation than it did a few years ago. This process is the direct descendant of W. Van D. Kelley's "Prizma," from which a large family of "processes" stemmed, amongst others "Kesdacolor," "Kelleycolor," "Magnacolor" and "Multicolor." W. T. Crespinel has stated that he was associated with Kelley, and that in 1928 he was interested in Multicolor. Crespinel claims to have been instrumental in developing a practicable bi-pack with the assistance of Du Pont. He recalls that they called the earliest bi-pack "Rainbow Negative"! Du Pont subsequently marketed this material as "Dupack." The first major feature was M.G.M.'s "Gallant Bess" photographed by John Boyle. There is no published information as to the precise processing procedure, but one side of duplitized film is doubtless toned Prussian Blue (ferro ferricyanide) and the other side is dye-toned by use of a suitable iodide mordant (B.P. 506,450). Alternatively uranium toning plus subsequent surface dyeing can be employed. The method of application is most likely to be by flotation of the film. All printing is necessarily carried out on step by step registering printers. Cinecolor is today processing both 16-mm. and 8-mm. prints. Reduction negatives are made from the 35-mm. original bi-pack negatives. It is stated that the company "has developed a three-colour system of producing colour prints. This system has been in use for the last three years, particularly for cartoons and blowups from 16-mm. Kodachrome." It is impossible to deduce from this description how the third colour is added, but it is most likely that imbibition printing is employed. In this case Cinecolor must possess a pin-belt transfer machine similar in principle to the Technicolor "I.B." machine.

The rather unexpected revival of interest in two-colour processes has brought Cinecolor into the foreground as a major competitor and today

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there is an output from the Cinecolor laboratories in Hollywood of no less than 120,000,000 ft. of print per annum. This extraordinary turn of events in the history of a colour film is to be explained partly as an economic phenomenon and partly as an answer to the insistent demand for a product possessing acceptable quality but which for its production does not necessitate a beam-splitter camera and the rather meticulous

<i>Title and Process</i>	<i>Producer</i>	<i>British Distributor</i>
"Adventure Island" (Cinecolor)	Pine-Thomas	—
"Who Filled Doc Robin" (Cinecolor)	Hal Roach	—
"Twin Sombreros" (Cinecolor)	Columbia	Columbia
"Song of Old Wyoming" (Cinecolor)	P.R.C.	Pathé
"Enchanted Forest" (Cinecolor)	P.R.C.	Pathé
"Wildfire" (Cinecolor)	Screen Guild	Exclusive
"Northwest Trail" (Cinecolor)	Screen Guild	Exclusive
"God's Country" (Cinecolor)	Screen Guild	Exclusive
"Home on the Range" (Magnacolor)	Republic	British Lion
"Man from Rainbow Valley" (Magnacolor)	Republic	British Lion
"Unusual Occupations" (Magnacolor)	Paramount	Paramount
"Popular Science" (Magnacolor)	Paramount	Paramount
"Gallant Bess" (Cinecolor)	M.G.M.	M.G.M.
"The Michigan Kid" (Cinecolor)	Universal	G.F.D.
"Curley" (Cinecolor)	Hal Roach	—
"Down California Way" (Trucolor)	Republic	British Lion
"Rough Riders of Cheyenne" (Magnacolor)	Republic	British Lion
"Last Frontier Uprising" (Magnacolor)	Republic	British Lion
"Santa Fe Sunset" (Magnacolor)	Republic	British Lion
"Trail to Alaska" (Cinecolor)	Monogram	—
"Colorado Serenade" (Cinecolor)	P.R.C.	Pathé
"The Caravan Trail" (Cinecolor)	P.R.C.	Pathé
"Death Valley" (Cinecolor)	Screen Guild	Exclusive
"Scared to Death" (Cinecolor)	Screen Guild	Exclusive
"Yosemite" (Cinecolor)	Screen Guild	Exclusive
"Here Comes Trouble" (Cinecolor)	Hal Roach	—
"Vigilantes Return" (Cinecolor)	Universal	G.F.D.

limitations and controls imposed by the more complex three-colour competitors. A two-colour process can in the nature of things only provide a minute proportion of the total range of colour sensations, and the undoubted satisfaction which has apparently been registered by uncritical audiences confirms the belief held by many colour film experts that the average film-goer is far less sensitive to the subtleties of colour than had been generally supposed. It does not seem that two-colour films have impressed even film technicians as being markedly inferior, or indeed different in any way, from films possessing a full colour gamut, and whilst producers can hardly be blamed for exploiting the advantages which this situation presents, it is difficult not to feel

some regret at the return to a stage of progress which marked an earlier phase in the evolution of the colour film. The low cost and ease of handling of two-colour film have attracted the attention of news film producers and an attempt is to be made to introduce regular issues in the United States. Two-colour films which have recently been produced are shown on the previous page.

With regard to the frequently advanced objection to film base carrying emulsion coatings on both sides as not being capable of being projected with perfect definition, R. H. Cricks has observed, "Mathematics disproves this idea. The thickness of the film base is .005 in.; assuming a 5 in. projection lens, this means a difference in image plane of $1\frac{1}{1000}$ the focal length. At a throw of 100 ft. this means a difference in focus of only just over 1 in.; quite normal angles of rake produce a difference of 2 or 3 ft. which passes unnoticed."

If colour prints made from bi-pack negatives suffer from lack of definition this may safely be ascribed to the scattering of the light in passing through the first emulsion to reach the back element of the bi-pack, for which reason every technical device must be adopted to ensure the maximum contact between the films. (18).

In 1945 Ansco announced three new types of 35-mm. professional colour film. These were Reversible Type 737, a soft gradation film intended to act as a master record. Reversible Type 732, a release positive printing film, and Type 132, a duplicating film. The former two types are available on nitrate or acetate film base. Later on a new "One-Strip Color Separation Film" was marketed, intended for making separation negatives from original reversal colour positives comprising the intermediate stage in the preparation of the monochrome positive masters for printing on Ansco Release Positive Type 732. Equal gammas for the three separations are a valuable characteristic of this product. Ansco Color has been used for a recent American film, "Sixteen Fathoms Deep." *Time* remarked that "In some scenes Ansco Color seemed far more natural than the *more expensive* Technicolor." This reference to comparative cost seems unlikely to be based on fact.¹

Thomascolor, of which there has been much written of late in American journals, is an additive system based on the patents of Richard Thomas. The optical system provides, it is claimed, four sub-standard parallax-free images within the area of a 35-mm. camera aperture (B.P. 453,221). A corresponding four-element projection lens includes means for effecting accurate registration on the screen of the part images. Thus Thomas offers only what has already been accomplished

¹ The first Ansco Color 35 mm. release (Monogram) was, "Climbing the Matterhorn," shot in 1946 by Irving Allen. "Alice in Wonderland" was completed in 1949 by the J. Arthur Rank organization. In 1948 A. & T. Productions produced in Paris, "The Man on the Eiffel Tower."

by the Roux optical devices, by Francita, by Bassani, and many others. The usual extravagant claims have been made. Whatever support the enterprise may succeed in attracting it is pretty safe to prophesy that its subsequent history will not be unlike that of its predecessors. Needless to say such optical accessories can always be "invented" and developed to the stage of an impressive demonstration. Between this point and the invariably threatened "revolution in the industry" is an abyss, and nobody has crossed it. One never can tell, however. Richard Thomas Enterprises is exploiting the process. In an article (19) in the *American Cinematographer*, on Thomascolor, a statement is made which the writer cannot forbear to quote. "In projection, the light from an ordinary lamp-house is ample. Since there is only white light projecting through the single emulsion transparent print and the light transmission is as great as with black-and-white, with no dyes to hold it back, the light transmission to the screen is nearly total. An unusual brightness range is the result." How happy Mr. Thomas must be!

In England the most promising development is today known as "Dufaychrome." This name was adopted by Dufay-Chromex after acquiring rights to what had hitherto been known as "British Tricolour." The private company which had sponsored the development of the patents of Jack Coote, F.R.P.S., a well-known authority on colour photography, was known as British Tricolour Processes Limited. Coote had contributed a considerable body of patents covering a complete situation, namely, a beam-splitter camera, a new type of negative, and several positive print techniques. The camera has been fully described in the June 1948 issue of the *Journal of the S.M.P.E.* The general design closely parallels the Technicolor instrument, and similar three-strip film stock is used. The print process makes use of a two-layer emulsion coating containing non-diffusing colour couplers, and this coating after printing is subsequently re-sensitized by quite a new technique, and printed. Development follows the general formulæ and technique of Agfacolor and similar processes, and is carried out as a single operation. The laboratory resources are to be rapidly expanded, but the present limited output is of first-rate quality and shows particularly good definition. Since the price is comparable to Technicolor an important future for Dufaychrome is assured.

The first extensive use of "Technichrome" was in making a colour film of the Olympic Games, 1948. This film was made for the J. Arthur Rank Organization Ltd. by Castleton Knight. Fig. 7A illustrates what must surely be the largest accumulation on record of cameras equipped for the exposure of bi-pack. The shortage of beam-splitter cameras and possible economies effected in production cost presumably led to this production being made in two-colour "Technichrome." Technichrome prints are made on the same machine used for Technicolor

HISTORICAL SUMMARY

three-colour prints, and in order to avoid any hold-up in the normal output the two-colour print is made from three matrices. Thus the yellow and magenta matrices are made from the same green-blue negative record. These two matrices can, if desired, be developed to different gammas, and this could result in a colour scale emphasizing red in the dark colours while the tones of increasing lightness would become more predominantly orange or yellow-orange in hue.

Outstanding Patents

<i>Patent Number</i>	<i>Patentee</i>	<i>Subject</i>
1868 F.P. 83,061	Ducos du Hauron.	" Les Couleurs en Photographie: Solution du Problème." (Paris, 1869).
1875 B.P. 4,362	Edwards, E.	First imbibition patent.
1876 B.P. 2,973	Ducos du Hauron.	Three-colour process.
1879 B.P. 2,969	Swan, J. W.	Relief Images.
1881 B.P. 1,436	Warneke, L.	Relief Images.
1895 F.P. 250,862	Ducos du Hauron.	Basic idea of bi-pack or " Poly-folium Chromodiallytique."
1897 B.P. 28,920	Bennetto, J. W.	" Semi-dialyte " system. Bi-pack and single film.
1897 B.P. 29,353	Butler, E. T.	Three-colour still camera.
1897 D.R.P. 98,799	Isensee, H.	Three-colour additive projection.
1898 B.P. 21,649	Friese-Greene, W.	Rotary colour shutter.
1898 B.P. 23,863	Davidson, W. Lascelles-	Three-lens camera.
1899 B.P. 3,560	Edwards, B. J.	Early three-colour still camera.
1899 B.P. 6,202	Lee and Turner.	Three-colour additive projection and special movement.
1900 B.P. 13,883	Friese-Greene, W.	Projection lantern for B.P. 21,649.
1900 B.P. 21,239	Sanger-Shepherd, E.	Early prism beam-splitter.
1901 B.P. 10,043	Davidson, W. Lascelles-	" Semi-dialyte " still camera.
1902 B.P. 13,468	Davidson, W. Lascelles-	Camera with three mirrors in front on lens.
1903 B.P. 3,729	Davidson, W. Lascelles- and Dr. Jumeaux, B.	Prism projection system.
1903 F.P. 328,321	Compagnie Générale des Phonographes Cinématographes et Appareils de Précision.	Production mécanique de sujets colorés pour rubans ou films de cinématographes.
1903 F.P. 331,859	Ditto.	Coloriage intermittent et combiné des bandes ou films cinématographiques.
1904 B.P. 7,179	Davidson, W. Lascelles-	Prism beam-splitters.
1905 B.P. 332	Pfenninger, O.	Projection lens and prism for 2- or 3-colour projection.
1905 B.P. 9,465	Friese-Greene, W.	The same.
1906 B.P. 25,908	Pfenninger, O.	Three sawn-off lenses.
1906 B.P. 26,671	Smith, G. A. and Urban, C.	" Kinemacolor " system.
1906 F.P. 364,369	Berthon et Gambs.	Projections cinématographiques reproduisant automatiquement et photographiquement les couleurs.

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<i>Patent Number</i>	<i>Patentee</i>	<i>Subject</i>
1906 F.P. 380,889	Compagnie Générale des Phonographes, Cinématographes et appareils de précision.	Machine pour colorier mécaniquement les films (images cinématographiques).
1906 F.P. 381,494	Joly, J.	Procédé de projection cinématographique en couleurs et dispositif le réalisant.
1907 F.P. 375,110	Berthon (et autres).	Perfectionnements aux projections cinématographiques en couleurs.
1907 F.P. 388,616	Dufay, Louis.	Procédé de fabrication d'écrans transparents à éléments polychrome pour la photographie des couleurs.
1907 F.P. 394,199	Société des Établissements Gaumont.	Machine à colorier les bandes cinématographiques par transport de la couleur.
1907 F.P. 394,236	Ditto.	Système de coloriage des bandes cinématographiques.
1908 F.P. 399,762	Berthon, R.	Perfectionnements aux procédés de coloriage des films cinématographiques.
1908 B.P. 453	Davidson, W. Lascelles-	Endless filter band.
1909 B.P. 10,611	Berthon, R.	Origin of Lenticular System.
1909 B.P. 5,945	Pfenninger, O.	Overlapping colour sectors.
1910 F.P. 422,640	Compagnie Générale des Phonographes, Cinématographes et appareils de précision.	Machine électrique à découper les bandes pochoirs pour le coloriage des films cinématographiques.
1910 F.P. 418,773	Société des Établissements Gaumont.	Dispositif assurant dans les machines à colorier les films cinématographiques, le repérage du pochoir et de la pellicule.
1910 F.P. 430,600	Berthon, R.	Méthode de photographie et de projection donnant l'illusion du relief, également applicable aux projections encouleurs.
1910 F.P. 434,002	Berthon, R. et Audibert, M.	Dispositif de prise de vues et projection cinématographique ou photographique en couleurs.
1910 D.R.P. 238,514	Lewy, E.	Double-coated film.
1911 F.P. 437,173	Société des Établissements Gaumont.	Cinématographe perfectionné pour projeter en couleurs naturelles d'après le procédé trichrome.
1911 D.R.P. 257,160	Neue Photographische Gesellschaft (Fischer).	Verfahren zur Herstellung von Farbenphotographien.
1911 B.P. 1,642	Bennett, C.	Colour development, and multilayer film.
		Two vertically superposed lenses. Origin of British Cinecolor, "Raycol," and such additive systems.

HISTORICAL SUMMARY

<i>Patent Number</i>	<i>Patentee</i>	<i>Subject</i>
1912 F.P. 450,930	Société des Établissements Gaumont.	Perfectionnement aux appareils cinématographiques pour projections en couleurs naturelles d'après le procédé trichrome.
1912 F.P. 448,565	Hamburger, A.	Perfectionnement dans la photographie des couleurs.
1912 B.P. 3,034	Urban, C.	Two mirrors behind one lens.
1912 F.P. 450,413	Urban, C.	Perfectionnement aux appareils photographiques employés dans la cinématographie en couleurs.
1912 B.P. 3,220	Société des Établissements Gaumont.	Three sawn-off lenses for camera.
1912 B.P. 10,150	Bennett, C.	Mirrors in front of objective.
1912 B.P. 24,159	Beck, C. and Bennett, C.	Origin of "Cinecolor" (British).
1912 B.P. 25,142	Player, D. W.	Rotating mirrors.
1913 U.S.P. 1,174,144	Hernandez-Mejia, A.	Double-coated film.
1913 F.P. 461,248	Cie Générales des Établissements Pathé Frères.	Système optique applicable aux appareils trichromes.
1913 F.P. 473,862	Ditto.	Procédé pour le découpage des patrons ou pochoirs, en partant des films cinématographiques.
1913 F.P. 466,781	Keller-Dorian, A.	Système de gravure pour projections photographiques reproduisant les couleurs de la nature.
1914 B.P. 24,698	Keller-Dorian, A.	Engraving celluloid for Lenticular film.
1914 F.P. 471,061	Société des Établissements Gaumont.	Appareil de prise de vues en couleurs par le procédé trichrome.
1914 U.S.P. 1,196,080	Comstock, D. F.	Photographs in color and method of making same.
1915 B.P. 13,429	Capstaff, J. G.	The earlier "Kodachrome" process.
1916 B.P. 100,082	Brewster, P. D.	Perforated mirror as beam-splitter.
1917 U.S.P. 1,573,595	Wall, Kalmus, Comstock, Westcott.	Dye composition.
1917 U.S.P. 1,573,596	Ditto.	Treating photographic emulsion and color sensitizing composition.
1917 U.S.P. 1,570,809	Westcott, W. B.	Treatment of cinematograph films.
1921 U.S.P. 1,677,309	Troland, L. T. and Ball, J. A.	Registering and cementing cinematographic films.
1921 U.S.P. 1,583,108	Ball, J. A.	Color cinematography.
1922 U.S.P. 1,596,808	Comstock, D. F.	Color cinematography.
1923 B.P. 217,557	Dufay, L.	Origin of "Dufaycolor."
1923 U.S.P. 1,696,809	Comstock, D. F.	Color cinematography.
1923 U.S.P. 1,516,824	Mannes, L. and Godowsky, L.	Color photography (Kodachrome).
1923 U.S.P. 1,607,440	Comstock, D. F.	Cinematographic film treating apparatus.

COLOUR CINEMATOGRAPHY

<i>Patent Number</i>	<i>Patentee</i>	<i>Subject</i>
1925 U.S.P. 1,677,310	Troland, L. T.	Cinematographic apparatus.
1925 U.S.P. 1,716,989	Troland, L. T.	Registration means for film-printing machines.
1926 U.S.P. 1,807,805	Sugden, B. and Tuttle, B. S. ¹	Preparation of colored reproductions by imbibition.
1927 U.S.P. 1,707,695	Troland, L. T. and Whitney, J.	Suction apparatus for imbibition printing.
1927 U.S.P. 1,707,710	Comstock, D. F.	Method and apparatus for imbibition printing.
1927 U.S.P. 1,873,259	Ball, J. A.	Color cinematogr. apparatus.
1928 U.S.P. 1,860,912	Troland, L. T.	Two-stage method of dyeing films and resulting product.
1929 U.S.P. 1,900,140	Sugden, B. and Tuttle, B. S.	Method of imbibition printing with pure primary colors, and product.
1929 U.S.P. 1,844,377	Troland, L. T.	Plural image optical system.
1929 U.S.P. 1,871,649	Ball, J. A.	Three-color cinematogr. camera.
1929 U.S.P. 1,919,673	Troland, L. T. and Eaton, R. D.	Technicolor process.
1929 U.S.P. 1,924,890	Troland, L. T.	Method of preparing gelatin blanks.
1929 U.S.P. 1,821,680	Troland, L. T.	Multilayer film and process of making.
1929 U.S.P. 1,924,901	Ball, J. A.	Color cinematogr. apparatus.
1929 U.S.P. 1,844,377	Ball, J. A.	Color cinematography.
1929 U.S.P. 1,928,714	Whitney, J. H.	Apparatus for affixing pins to metal belts.
1930 U.S.P. 1,974,935	Troland, L. T.	Film covering method and apparatus.
1930 U.S.P. 1,928,709	Troland, L. T.	Multilayer film and method.
1930 U.S.P. 1,996,928	Mannes, L. and Godowsky, L.	Sensitized photographic elements and process of making same (Kodachrome).
1930 D.R.P. 546,470	I.G. Farben.	Verfahren zur Überführung von photographischen Silberbildern durch Oxydation und Verwendung von Leukoverbindungen.
1930 U.S.P. 1,889,030	Ball, J. A.	Multicolor photography with bi-packs.
1930 U.S.P. 2,013,116	Troland, L. T.	Photographic matrix.
1931 U.S.P. 1,923,764	Troland, L. T.	Photographic gelatine relief.
1931 U.S.P. 1,926,255	Ball, J. A.	Subtractive color photography.
1931 U.S.P. 200,058	Ball, J. A.	Three-color photography.
1931 U.S.P. 1,919,673	Troland, L. T. and Eaton, W. S.	Photographic relief.
1931 U.S.P. 2,032,401	Clark.	Color photography.
1932 U.S.P. 2,159,884	Mannes, L. and Godowsky, L.	Color photography.
1933 U.S.P. 1,993,576	Troland, L. T.	Monopack process.
1933 U.S.P. 2,068,879	Troland, L. T.	Photographic relief process.
1934 F.P. 767,707	Siemens et Halske.	Procédé de production de copies de films à trame lenticulaire.

¹ Miss B. Sugden and Mrs. B. S. Tuttle of Technicolor Mot. Pict. Corp.

HISTORICAL SUMMARY

<i>Patent Number</i>	<i>Patentee</i>	<i>Subject</i>
1934 F.P. 786,857	De Lassus.	Procédé et dispositif pour la copie de films gaufrés sur films gaufrés et le projection correcte de ces copies.
1934 U.S.P. 2,079,470	Sugden, B. and Tuttle, B. S.	Method of making imbibition films.
1934 U.S.P. 2,046,320	Burbank.	Method of making hardened gelatin films and resulting product.
1935 B.P. 487,941	I.B. Corporation, Weaver, E. H., Imlay, R.	Imbibition printing machine.
1937 U.S.P. 2,072,091	Ball, J. A. and Rackett, G. F.	The Technicolor camera.

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The Theoretical Basis

Th' invention all admired, and each, how he
To be th' inventor missed; so easy it seemed,
Once found, which yet unfound most would have thought
Impossible.

MILTON.

THROUGH the agency of our sense organs we perceive certain aspects of the physical universe. The eye is a specialized instrument for responding to a certain limited range of radiant energy which we call *light*. The ear responds to molecular vibrations, as of air, or of water, or of a solid.

During the last fifty years men of science (or perhaps the men of applied science, called "inventors") have solved most of the problems of recording and reproducing the physical stimuli which originate our sensations.

Reproductive processes have two aspects:

1. *Recording.*
2. *Reproducing.*

In the case of colour photographic processes, these may be alternatively expressed as:

1. *Analysis.*
2. *Synthesis.*

Generally the apparatus by which recording is done copies in much of its constructive detail one of the sensory organs. If we record sound we use an artificial ear, the microphone. If we record light we use an artificial eye, the camera lens and film.

Between the analysis and the synthesis there can be inserted a transformation process by which the original physical stimulus may be temporarily changed into another mode of energy transmission. This may be for reproduction at a distance. Hence in telephony sound waves at a given place are transformed into electrical impulses and transmitted by a suitable conductor to a distant point, where they may be transformed again by a reproducer into air waves corresponding to the original sounds. The problem of television is still more complex, for here we are transforming the vibrations of light, comprising every point in an image, thirty or more times per second, into modulated electrical waves of a type suitable for radio broadcasting, and subse-

quently retransforming these at some distant point into light spatially so disposed as to form an image of the original subject.

Recording images of the visible world in colour has proved a particularly difficult task. As colour is a special quality of vision, before much could be done some working theory had to be evolved as to the mechanism of colour vision. In the apparatus and theory of colour photography we have a very pretty example of a recording mechanism designed to function similarly to the sensory organ concerned.

Some twenty-five years after the Swedish chemist Karl Wilhelm Scheele (1742-86) had first noted the variable darkening of silver chloride by the different rays of the spectrum, and in the same year (1802) that Thomas Wedgwood published in the *Journal of the Royal Institution* an account "of a method of copying paintings upon glass, and of making profiles by the agency of light upon nitrate of silver," Dr. Thomas Young had given his paper before the Royal Society in which he had hypothesized that colour perception depends on the presence in the retina of three kinds of nerve fibres whose response to the stimuli of light waves gives rise to the sensations respectively of red, green, and violet. It was nevertheless not until twenty years after William Henry Fox Talbot (1800-77) announced the discovery (1834) of photographic printing of images upon paper¹ that Clerk Maxwell (1855) suggested means whereby photography in colours might be achieved by a three-colour photographic analysis, based upon the three-colour theory of colour vision.² (1)

Clerk Maxwell, Ducos du Hauron, and other pioneers must have approached the problem somewhat thus: By means of photography it is possible to record images of the visible world in gradations of the scale white—grey—black. How can the photographic process be made to conform to the response of the eye in all respects, including its sensations of colour? Now, it has been shown by experiment that three colours of the spectrum can be chosen from which all other colours can be matched by mixing various proportions of these three (Maxwell had chosen red, green, and blue). The experiment of the mixing of lights composed of isolated wavelengths of the spectrum chosen at points where the red, green, and blue hues seemed most intense had shown that varying proportions of these matched other parts of the spectrum in such a way that each primary was spread over a region of, roughly, a third of the spectrum. Evidently, visible light must be divided into three groups of waves, each of which must be caused to form a record of the proportion in which each of the mixture

¹ Joseph N. Niepce, French physicist (1765-1833), had begun his researches upon photography as early as 1814. Later he worked in association with Louis Jacques Mande Daguerre (1789-1851), the outcome of their researches being the "Daguerreotype" process.

² *Proc. Roy. Soc.*, 1855, 21; *Trans. Roy. Soc.*, Edinburgh, 1857, 21, 275.

primaries would be present to match the original light coming from a given part of the image. Thus the light would have to be filtered three times. The simplest kind of analyser will be a coloured glass or a piece of gelatine dyed with an appropriate dye or dyes. Red, green, and blue filters must be placed one at a time in front of the lens of the camera, or somewhere in the optical system, to act as selectors, or analysers, during the time of the exposure of the sensitive photographic emulsion to an image of the subject. Next, a photographic emulsion must be made which is capable of recording radiation of any colour (that is, sensitive to light throughout the spectrum) which the analyser may transmit. Then let three pictures be taken of the subject through the three analysis filters. One negative will bear various densities representing the amount of the red sensation-causing light in the original subject, another the green record, and a third the blue record. Then let us next make ordinary black-and-white positives from these negatives. These positives will be transparent in proportion (neglecting certain failures in the functioning of the photographic process) to the amount of light recorded by each of the negatives. If with a triple "magic lantern" these transparencies are projected one on top of the other upon a screen, projecting the positive of the red record through a red filter, the green through a green, and the blue through a blue filter, the respective coloured lights in their varying analysed quantities will thus be added together, and the final combined image should recompose the original colours of the subject photographed. Though the first attempts were not very successful, the combined pictures of coloured light did roughly resemble the original subject. This method has become known as the **Additive Process**.

By the means described above the three positives were modulating by their various densities the stimulation value of red, green, and blue light in all parts of the original image, and the colour filters were providing suitably chosen trichromatic stimuli. Every part of the triple combined image represented various proportions of the chosen trichromatic stimuli. Where all three plates happened to be transparent in the same part of the picture there was transmitted to the screen and from thence reflected to the eye of the observer the full value of red, green, and blue light from the light-sources in the three lanterns. The resulting sensation derived from that part of the image was white. Other relative proportions of the three stimuli gave rise to nearly every other colour sensation.

When these principles have been grasped the theory of the subsequent attempts to solve the problem will be readily understood. First, there must be the analysis of the light into three parts of the spectrum (or three spectral distributions constituting stimuli confined to three parts of the spectrum which, by additive mixture in varying proportions, can be made to match a large range of colours); next,

the photographic recording of this triple analysis; finally, the reproduction, or synthesis, accomplished by recombination of the trichromatic stimuli in their original proportions.

Before describing variations of analysis methods it is necessary to refer to an alternative method of synthesis. This is best understood by realizing that there must be two ways of recombining the primary elements, or trichromatic stimuli:

1. Adding three suitably chosen coloured lights together, starting with no light.
2. Starting with white light (namely, a combination of the whole range of visible radiation) and *subtracting* from it various amounts of trichromatic stimuli.

The latter alternative is known as the **Subtractive Process**.

The principle had been familiar to artists for centuries, and their practice had been the origin of the false assumption that red, yellow and blue were the primary visual stimuli. Those three colours which are found to be correct subtractors of each of the primary light-sources must necessarily be reflectors, or transmitters, of the remaining two-thirds of the spectrum. Thus we find that the three subtractive primaries are:

1. **Red** subtractor—reflects (or transmits) green and blue.
2. **Green** subtractor—reflects (or transmits) red and blue.
3. **Blue** subtractor—reflects (or transmits) red and green.

The three subtractive primaries are therefore:

1. **Cyan** (green and blue light reflected or transmitted).
2. **Magenta** (red and blue light reflected or transmitted).
3. **Yellow** (red and green light reflected or transmitted).

Ducos de Hauron was the first to define clearly the relation between the three-colour separation negatives and the production from them of a subtractive print or colour transparency. The gradations of a black-and-white positive print, as we have remarked, made from a colour separation negative, represent the light which was *not* recorded on the negative. Used as a transparency placed in front of a source of light it can be made to function as an absorber of the particular primary colour recorded on the negative from which it was made. To this end the positive print must be rendered in such a colour as will be transparent to the remainder of the spectrum unrecorded on the negative, and opaque to the colour which was recorded. So that from the three negatives three positives are made, each in the colour complementary (namely, the balance of the spectrum) to the light recorded on the negative used. When assembled in superposition, we have in fact made an infinitely variable three-colour subtractive

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filter which can be placed between the eye and a source of white light. Thus the red filter negative has to be printed in green-blue (cyan), the green filter negative in red-blue (magenta), and the blue filter negative in red-green (yellow).

The additive and subtractive methods of finally recomposing the three-colour image will be further simplified for the non-technical reader by reference to Figs. 8 and 9. In Fig. 8 is shown a diagram of the additive process. The three projection positives are replaced by three density wedges or scales which in this case have a diagrammatic significance only. Let us suppose that each of these wedges can be moved up and down behind its own projection lens. And let us suppose that the lenses are so disposed that their projected images are correctly superposed upon a screen. In the diagram the primary

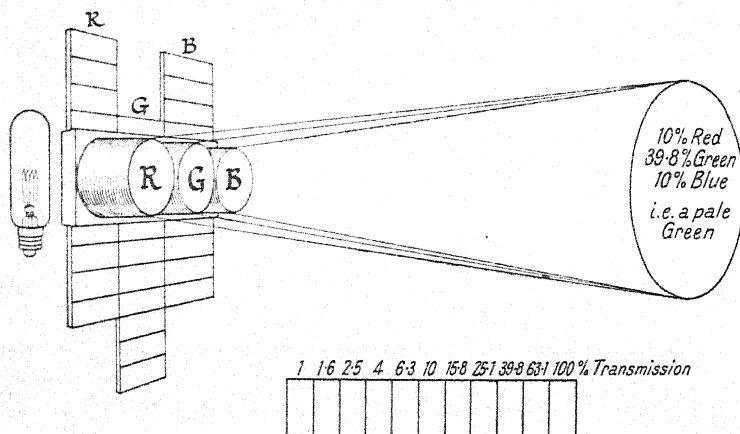


FIG. 8.—Diagram of the additive process.

colour filters are placed in front of their respective lenses. It is assumed that one or more light-sources are placed behind the wedges to supply the light for projection. Suppose that the percentage of light transmitted by each of the wedges were divided into the following eleven values (see table):

TRANSMISSION FACTOR	
1.0 per cent.	15.8 per cent.
1.6 " "	25.1 " "
2.5 " "	39.8 " "
4.0 " "	63.1 " "
6.3 " "	100 " "
10.0 " "	

In the position in which the three wedges are shown in the diagram, the transmission factors of the steps opposite the respective lenses are:

THE THEORETICAL BASIS

Red	10.0 per cent.
Green	39.8 " "
Blue	10.0 " "

Such a colour would be a pale, whitish green. It is obvious that by sliding these wedges up and down an enormous number of colour mixtures is possible. The principle is identical when three positive pictures are projected one on top of the other, the steps of the wedges being then replaced with infinitely variable densities. Of course, the colour filters could equally well be stained evenly all over the surface of the black-and-white wedges, and, as we shall see, this method was adopted by some of the earlier workers employing additive methods of synthesis.

In Fig. 9 the principle of the subtractive process is diagrammatically presented, but in this instance it will be observed that the wedges are placed *one in front of the other*. Each wedge consists of a series of coloured steps, one end of the wedge being white, while the other end is a step of concentrated colour with intervening colour steps graded between. Each wedge is comprised of gradations of one of the *primary subtractors*.

Thus we have a green-blue (cyan) or minus red wedge. This is supposed to transmit all the green and blue along its whole length but to absorb varying percentages of red. Similarly, we have a red-blue (magenta) or minus green wedge and a red-green (yellow) or minus blue wedge. The percentage of red, green, or blue absorbed is in each case:

ABSORPTION FACTOR

0.0 per cent.	93.7 per cent.
36.9 " "	96.0 " "
60.2 " "	97.5 " "
74.9 " "	98.4 " "
84.2 " "	99.0 " "
90.0 " "	

In the position the wedges occupy in the diagram it is supposed that the projection system is so arranged that the light is limited to the width of one wedge step. The particular steps which are superposed in the diagram have the following absorption factors:

93.7 per cent.	red
90 " "	green
0 " "	blue

Considering the incident light to be made up of 100 parts of each of these three colours, the amounts transmitted are clearly

100 - 93.7 =	6.3 parts	red
100 - 90 =	10 " "	green
100 - 0 =	100 " "	blue

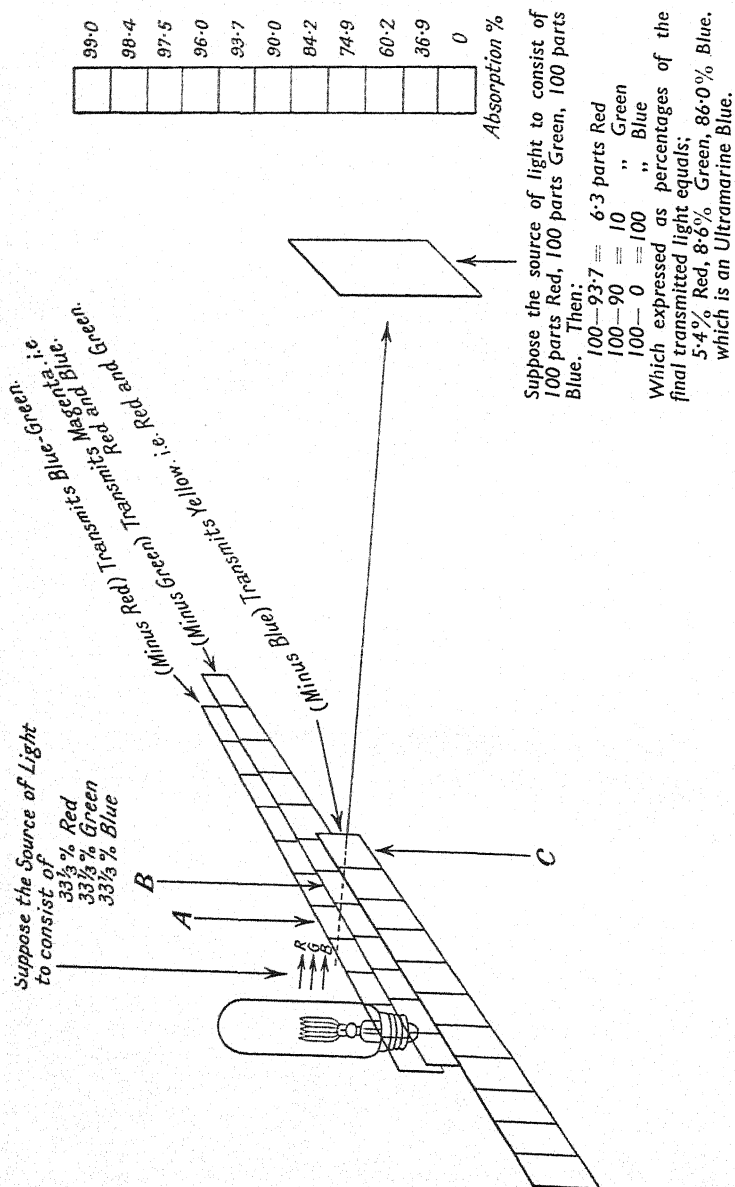


Fig. 9.—Diagram of the subtractive process.

which, expressed as percentages of the final transmitted light, equals

5.4	per cent.	red
8.6	"	green
86.0	"	blue

This colour would be a very fine cobalt¹ blue. The three wedges here represent diagrammatically the three superimposed printings, emulsion layers, or other continuous colour printings used in a subtractive process. As in the additive process, an enormous number of colour mixtures is obtainable, the range being limited only by the approximation of the primary subtractors to ideal requirements—namely, that each subtractor should, at its maximum absorption, completely absorb the primary and perfectly transmit the remaining two-thirds of the spectrum. As we shall have occasion to point out later, it is unfortunate that the colouring matters available for the different processes approximate only roughly to these requirements, an inherent defect which is one of the causes of whatever failure the three-colour subtractive process may exhibit in the perfect transformation of the values present in the recording negatives.

THE RECORDING AND REPRODUCTION SEQUENCE

The proper comprehension of colour cinematography requires that one should constantly bear in mind the series of transformations which take place between the incidence of the light which illumines the object being photographed and the last stage of all, in which the light reaches the eye from what we will call the *reproduction plane*. For we are endeavouring to stimulate an observer's eye by radiation (reflected from a white screen, or from a two-dimensional surface of some kind) intended to produce approximately the same sensations of vision as the original light would have done.

The following are the principal stages or aspects of the recording and reproduction sequence:

1. THE PRIMARY LIGHT-SOURCE.
2. THE SECONDARY LIGHT-SOURCE.²
3. TRICHROMATIC ANALYSIS.
4. THE PHOTOCHEMICAL RECORD.

The Recording Plane. (Trichromatic record.)

5. THE POSITIVE REPRODUCTION IN ADDITIVE OR SUBTRACTIVE PRIMARIES.
6. THE PROJECTION LIGHT-SOURCE.
7. THE SCREEN REFLECTOR.

The Reproduction Plane.

8. THE PSYCHICAL AND PHYSICAL RESPONSE TO RADIANT STIMULUS.

The accompanying diagram (Fig. 10) conveys schematically the relationship of the different stages to each other, but it is obvious that

¹ Or ultramarine.

² A "secondary source" can be defined as a body or object transmitting or reflecting light falling on it from any other source (primary or secondary).

COLOUR CINEMATOGRAPHY

small errors at any stage must bring about a serious variation between sensations "A" and "B." These errors will be multiplied progressively from stage to stage with important consequences. Throughout, it is a matter of most delicate balancing of three factors. Sensation "A" never does match sensation "B" except under conditions which are almost impossible to realize in practical cinematography. But the

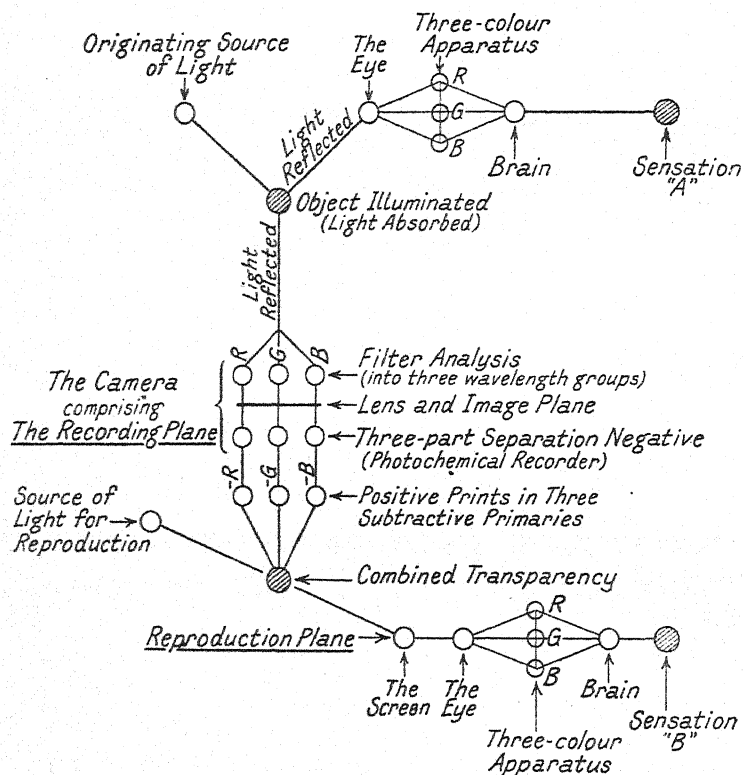


FIG. 10.—The recording and reproduction sequence in the subtractive process.

achievement of equivalence between the two sensations must always be our objective, and the causes of failure must be carefully studied at each stage of the transition.

The capacity of a commercial process to reproduce colours can be gathered by consideration of the results tabulated by R. H. Bingham of Ansco. In Table 1 we have the chromaticity co-ordinates of five Munsell samples and their reproductions by the material developed, respectively, to a gamma of 1.0 and 1.5. It will be observed that the

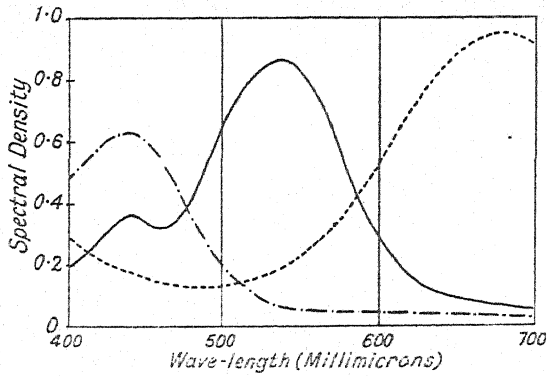


FIG. 11.

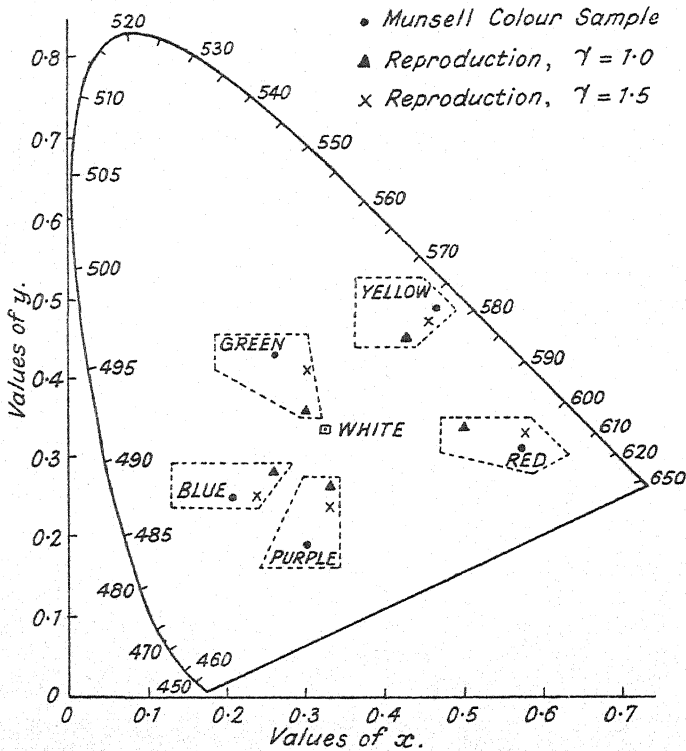


FIG. 12.—Chromaticities of reproductions calculated at two different contrasts. Note: Dotted lines indicate Sample and reproduction points associated with each colour (R. H. BINGHAM).

COLOUR CINEMATOGRAPHY

higher gamma reduces the luminance but increases the saturation of the reproduction colours.

TABLE 1

		Y	x	y
Munsell Sample N10	Sample	1.000	0.322	0.338
	$r=1.0$	1.000	0.322	0.338
	$r=1.5$	1.000	0.322	0.338
Red 5R 4/14	Sample	0.131	0.572	0.314
	$r=1.0$	0.117	0.499	0.337
	$r=1.5$	0.048	0.578	0.329
Yellow 5Y 8/12	Sample	0.570	0.466	0.488
	$r=1.0$	0.536	0.426	0.451
	$r=1.5$	0.397	0.458	0.471
Green 5G 5/8	Sample	0.190	0.258	0.431
	$r=1.0$	0.153	0.298	0.356
	$r=1.5$	0.061	0.304	0.410
Blue 5B 4/8	Sample	0.113	0.205	0.252
	$r=1.0$	0.098	0.257	0.282
	$r=1.5$	0.032	0.235	0.254
Purple 5P 4/12	Sample	0.121	0.299	0.191
	$r=1.0$	0.140	0.331	0.263
	$r=1.5$	0.054	0.331	0.237

In these calculations the illuminant was taken to be daylight at 6,000° K. The three dyes used in the process are shown in Fig. 11. It will be seen that the approximations to the originals are in most cases singularly near when the immense difficulties involved are taken into consideration (Fig. 12). Let us now proceed to examine in some detail the various stages of what we have called the Recording and Reproduction Sequence.

1. THE PRIMARY LIGHT SOURCE (FOR RECORDING)

NATURAL ILLUMINATION: DAYLIGHT, SUNLIGHT, ETC.

It is generally supposed that the colour-temperature¹ of average daylight varies over a wide range. This is not so. Only under exceptional conditions is there considerable shift, otherwise it would be necessary to make constant adjustments by means of compensating filters. It has been shown by F. H. G. Pitt and E. W. H. Selwyn [1]

¹ The colour temperature of a light source is the temperature at which a full radiator would emit radiation of substantially the same spectral distribution in the visible region as the radiation from the light source and which would have the same colour. *Chromaticity* is the colour quality of a stimulus, without reference to the luminance, as defined by two of the chromaticity coordinates (usually x and y).

that the integrated light from a number of exterior subjects reflected into a camera lens is

representable on the average by a colour-temperature of $4,800^{\circ}$ K. and that none of the subjects departed markedly from this, although components of the subjects such as grass and sky are some way removed from white. The overall colour remains the same during the day except towards sunset, when the light rapidly becomes more blue.

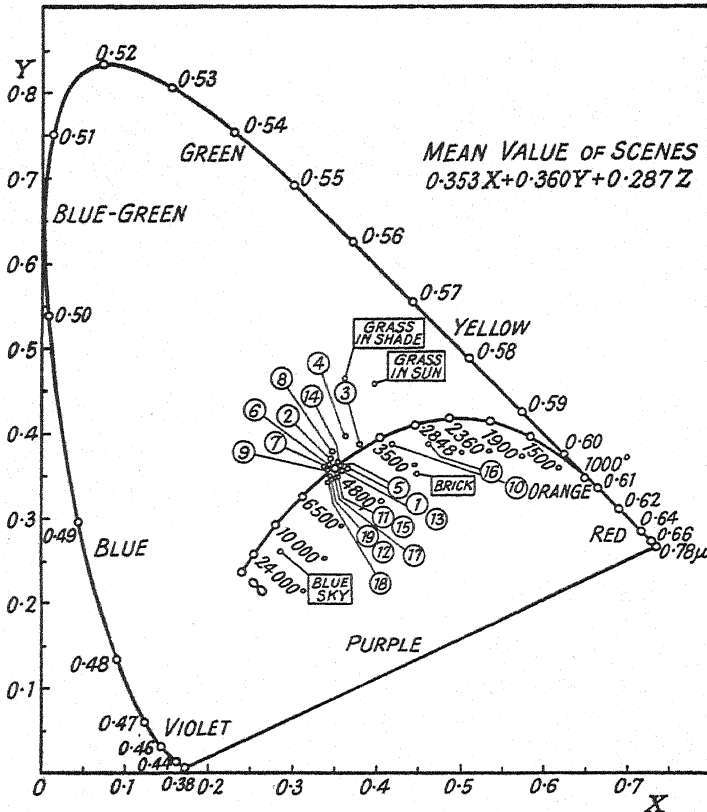


FIG. 13.—The integrated colour of typical exterior subjects (Pitt and Selwyn).

As will be seen from Fig. 13, the interesting fact emerged that the colours of the various scenes followed the locus of the black body radiators of different temperatures rather closely and all cluster about the point representing $4,800^{\circ}$ K. It can thus be concluded that the integrated colour of the average subject is very nearly white, and that it will be represented by a curve of roughly the same shape as the energy curves in Fig. 14, and will be approximately between the limits shown by the curves from $5,500^{\circ}$ K. and $3,500^{\circ}$ K.

The authors of this paper made this very interesting observation:

During the period of investigation, measurement was made of the extent of the change in overall colour of a typical object during the day. The prevalent idea is that the colour gets bluer as the sun tends towards its zenith, and then gets less blue when it passes this point. No appreciable change of colour was detected during the day, but there was a striking effect close on sunset. This change, illustrated in Fig. 15, not only is most marked but also occurs fairly rapidly. In general, the scene, as a whole, commences to get bluer about twenty-five minutes before sunset and the whole change occurs in approximately fifteen minutes, and then, as far as is measurable, the colour remains constant in quality. Two completely different scenes, a red building and a seascape measured on the 6th and 15th September respectively, gave almost identical results. This experiment, repeated in November, the subject being

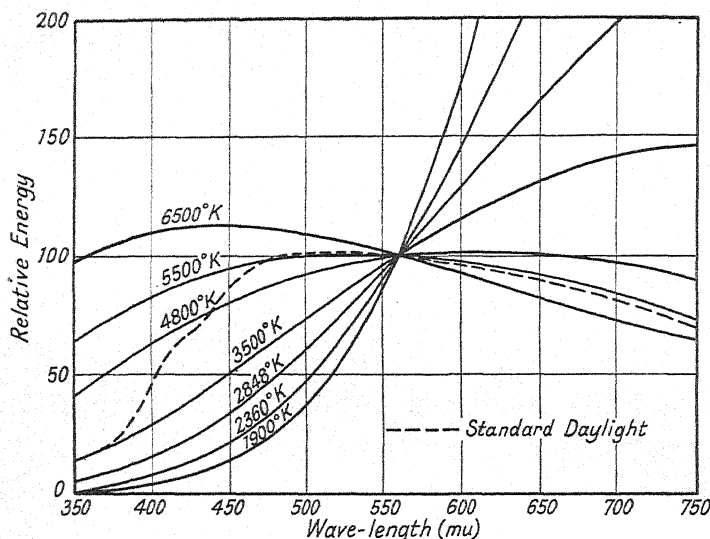


FIG. 14.—Energy curves of various illuminants.

a small green field, with trees and red buildings in the background, confirmed the earlier measurements. These results suggest that the frequent statement that *the colour of scenes gets redder in the evening is erroneous*. In fact, approximate constancy of the colour of the total light from sun and sky falling on a horizontal surface was a result arrived at by Kimball in 1924 [2] and 1928 [3] by calculations based on the colour of sunlight and of skylight and their relative intensities at different times of the day. Also the calculations predicted a change towards blueness when the sun was close to the horizon. What happens is that the *direct* light from the sun becomes more red as sunset approaches, but this direct light is diminishing in intensity. The scattered light, which is bluish and coming from the whole area of the sky, also illuminates the subject, and although diminishing in intensity does so at a slower rate than the direct light, and the reddening of the direct light is not enough to counterbalance the blue of the scattered light. Very similar results have been reported by Priest [4], who finds a rapid decrease in colour-temperature at sunrise.

THE THEORETICAL BASIS

More sensitive methods of measurement, using photoelectric apparatus, confirmed the facts that the overall colour of a typical subject remains unaltered during the day and that the only marked change in colour occurs about half an hour before sunset.

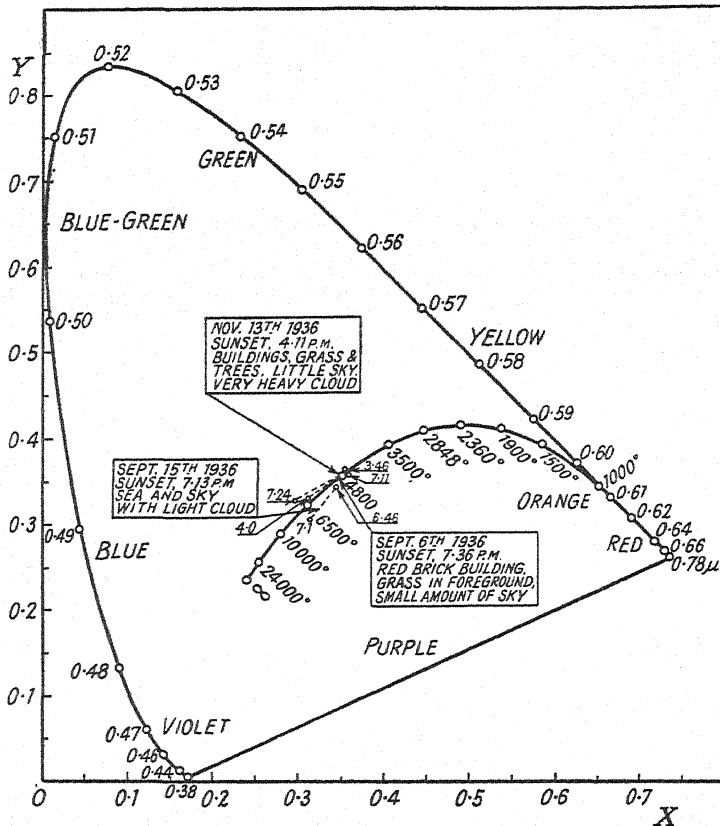


FIG. 15.—Change of colour immediately before sunset
(Pitt and Selwyn).

References

- (1) PITT, F. H. G., and SELWYN, E. W. H., "Colour of Outdoor Photographic Subjects," Kodak Communication No. H.641 from the Research Laboratories, Wealdstone, Middlesex.
- (2) KIMBALL, H. H., *Monthly Weather Review*, 52, 473-9, 1924.
- (3) KIMBALL, H. H., International Commission on Illumination, 501-15, Sept. 1928.
DAVIS, R., and GIBSON, K. S., *Misc. Pub. Bur. Standards*, No. 114, 1931.
DAVIES, E. R., *Proc. Brit. Kinemat. Soc.*, No. 17, 3-18, 1933.
- (4) PRIEST, I. G., *J.O.S.A.*, 78-9, 1923.

ARTIFICIAL ILLUMINANTS

Artificial illuminants may be divided into four categories:

- A. Illuminants having discontinuous spectra.
- B. Illuminants having fairly continuous spectra.
- C. Illuminants having continuous spectra.
- D. Illuminants having continuous and discontinuous spectra mixed.

A. Illuminants having Discontinuous Spectra

Incandescent gases emit only certain wavebands, generally very narrow, or even one or two wavelengths. Such line spectra serve as the basis of spectrum analysis. In gaseous electric discharge tubes there may be great gaps in the spectrum of the emitted light. The overall colour is the integral sensation of the retinal stimulation by the radiant energy of the various wavelengths present.

Examples

Mercury Vapour Tubes (old low-pressure tubes).

The visual appearance is a green-blue white.

(Lines at 0.578μ , 0.546μ , 0.436μ , 0.405μ .)

Neon Tube.

The visual appearance is a pinkish red.

Moore Nitrogen Tube.

The visual appearance is a pale pink.

Such illuminants are useless for colour photography, in spite of the fact that some inventors have suggested balancing several different discharge tubes in such a way as to imitate the white light of an equal energy spectrum.

The emission of both the neon and nitrogen tubes is so feeble that neither lamp is of any value for cinematography.

The sodium vapour lamp need not be considered, since the radiation consists almost entirely of 5,890 Å. and 5,896 Å. (spectrum yellow), which is useless for colour photography.

B. Illuminants having Fairly Continuous Spectra

Certain types of arc lamp using specially cored carbons have a very crowded line spectrum with powerful emission often in the ultra-violet and considerable gaps in the visible region.

C. Illuminants having Continuous Spectra

Examples

The Tungsten Incandescent Filament Gas-Filled Lamp

The commercial tungsten lamp is a satisfactory source of light for colour photography in the motion picture studio, but it is far from being ideal, since we start with an overwhelming predominance of red, orange, and yellow rays (Fig. 16). Hence, at the beginning of our recording stage we have unbalanced quantities of the three primaries.

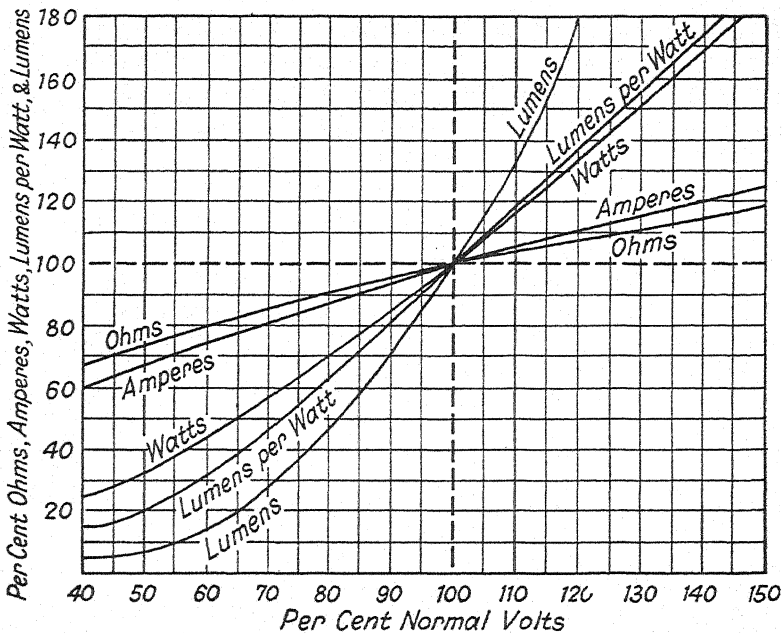


FIG. 16A.—Effects of operating a tungsten filament lamp at other than rated voltage. (Courtesy, G.E.C.—U.S.A.)

Using lamps run at the voltage for which they were designed, namely for the maximum life of the lamp, the position is that the red, green, and blue rays must be present in such a proportion as will upset the balance of the photographic effect. The balance has to be restored at a later stage, and this must entail loss of efficiency, since the excess rays must be eliminated. This is generally done by altering the analysis filters, taking into consideration their relation to the sensitiveness of a given emulsion to red, green, and blue.

But there is an alternative solution of this problem which has been given a practical trial in American studios. This is to run the lamps

at such a voltage as will reduce their useful life but result in a considerable rise in the temperature of the incandescent tungsten filament. The requirement is to obtain not only a larger proportion of blue and violet light in comparison with the emission of red and orange, but also a greater volume of light for a given wattage, since the amount of heat on a set is governed chiefly by the total wattage in use.

Comparing a lamp of the usual type operating at $2,980^{\circ}$ K. with an overrun lamp burning at a filament temperature of $3,435^{\circ}$ K., the increase in blue-violet radiation is no less than 140 per cent. (Fig. 17).

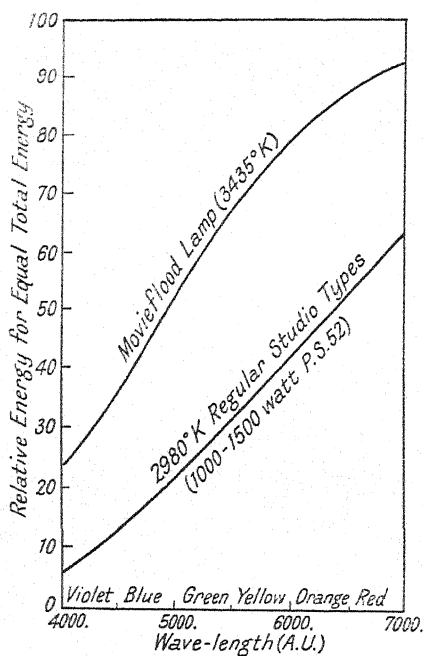


FIG. 17.

Thus, by the simple process of operating the lamps on over-voltage, we receive not only a greatly increased volume of light, but also light of an improved quality for the purpose of colour photography, and that at the minimum wattage. To be sure, there is still some excess of red-orange which must be filtered out, but the losses are very much reduced. Such filtering can be accomplished by a suitable colour filter in front of the camera lens, by gelatine or glass screens in front of the light-sources, or possibly by the use of coloured bulbs.

Reflectors found efficient in America are such as the Mole-Richardson "Rifle" Unit. It is capable of directing 50-60 per cent. of the light

within angles wherein it can be used. Fig. 19 illustrates the candle-power¹ distribution obtained from a 2,000-watt lamp of the type developed for colour photography, and Fig. 18 that from a standard 1,500-watt lamp usually employed in the studios. The 1,500-watt lamp directed 17,000 lumens in the 60° useful angle, whereas the 2,000-watt lamp gave 32,000 lumens in the same angle, an increase of nearly 100 per cent. over the standard type.

When overrun these lamps have a life of from 15 to 18 hours. The 2,000-watt lamp is used for general lighting, but for modelling or spot work the 5-KW. and 10-KW. lamps are used. They are identical to the standard lamps, but are rated at 105 volts. Such lamps normally operate at 29-30 lumens per watt; and the over-voltage to which they

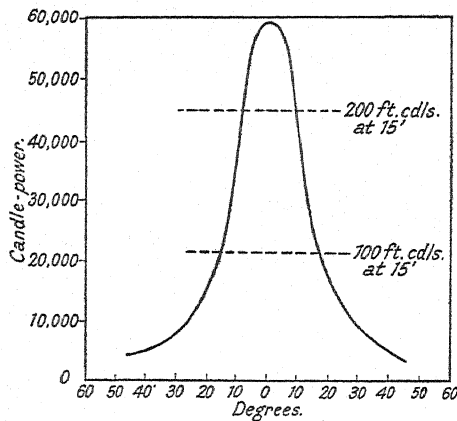


FIG. 18.—Normal 1,500-watt lamp in Mole-Richardson "Rifle" Reflector Unit.

are submitted when operated on 120-volt circuits not only increases the quantity of light emitted, but also makes the quality of the radiation the same as that of the specially designed "photoflood" type of lamp.

In Fig. 20 is shown the distribution of visible energy radiated from the tungsten filament at various temperatures. The area beneath each curve represents the energy in the visible light radiated at the temperature indicated. These curves show that as the temperature of the filament is increased the relative increase of energy in the shorter wavelengths is much greater than in the long wavelengths. This is of special significance to colour photographic illumination.

¹ 1 equivalent foot-candle (e.f.c.) is the brightness of a perfectly diffusing surface of 100 per cent. reflection factor receiving an illumination of 1 foot-candle.

$$1 \text{ e.f.c.} = \frac{1}{\pi} \text{ candles/sq. ft.}$$

R. E. Farnham notes that

The widely used 1,000- and 1,500-watt lamps operate at an efficiency of 21 lumens per watt, but if the efficiency is increased to 33 or 34 lumens per watt the percentage of blue-violet radiation is about doubled. A 1,500-watt lamp operating at the latter efficiency has a visual light output of a 2,250-watt lamp. The life of these lamps is roughly 12-15 hours. An analysis of costs shows £16 worth of lamps is sufficient to light an average set and permits the exposure of £480 worth of film. This is considered a satisfactory ratio. While preparing for shooting they should be run

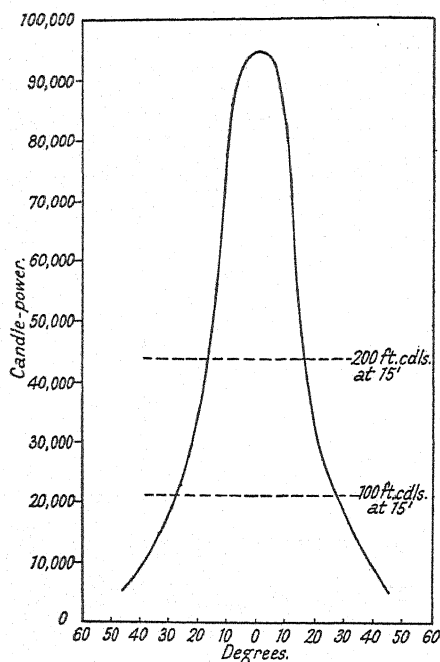


FIG. 19.—Candle-power distribution obtained from a 2,000-watt lamp overrun, showing an increase of 100 per cent. over the standard type Mole-Richardson "Rifle" Reflector Unit.

at 90 volts. Because of the relatively great light output, the wattages for colour sets are of the same order of magnitude as for black and white.

Further study of this problem during 1934 brought out the further requirement that it is frequently desirable to employ on a particular set more than one type of illuminant, such as the white-flame arc and tungsten lamps, or incandescent lamps and daylight. The colour of the light must therefore be corrected at the source.¹ A group of persons in variously coloured costumes and settings were photographed first by the light of the white-flame arc and then by the high-efficiency Mazda lamp with each of a series of gelatine filters, changing back to the control source each time before a new filter was put in place. The results indicated that "Brigham" shade No. 26 was the correct filter.

¹ In order to get balanced negatives through the standard three-colour filters.

Corning Glass Works were requested to copy the gelatine filter as closely as possible, and they produced a glass now known as Corning's Lunar White No. 570. Actual density measurements from sensitometric data taken at the time the colour photographs were made show the light from this combination of lamp and filter to have 100 units of red, 102 units of green, and 99 units of blue—an almost perfect white (Fig. 21).

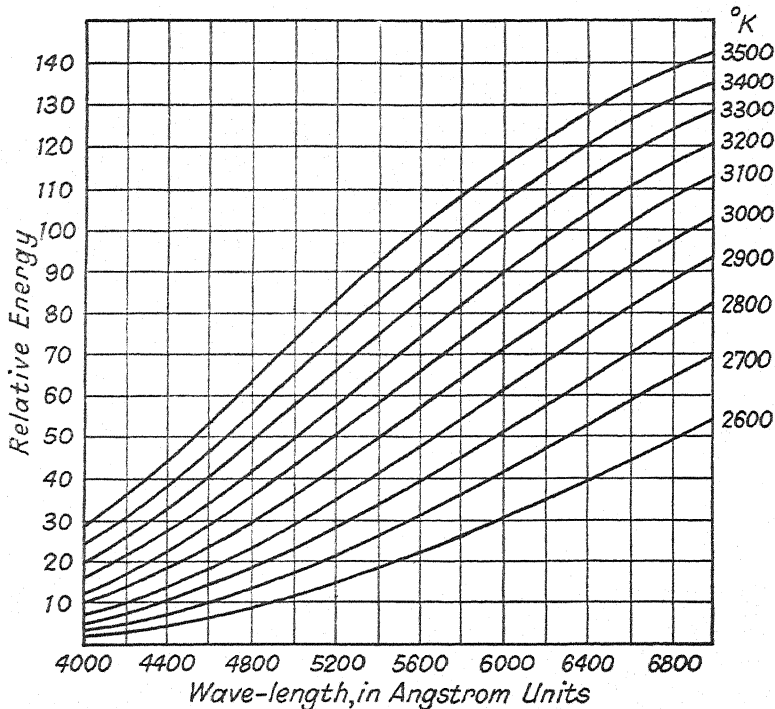


FIG. 20.—Spectral energy distribution in the visible region from tungsten filaments of equal wattage but different temperatures. (Linderman, Handley, and Rodgers.)

At a meeting of the Society of Motion Picture Engineers held in 1935 Mr. Mili said: "Tests made in our laboratory indicate a 5 per cent. drop in voltage will lower the colour-temperature of the illuminant by about 75° . In other words, if the colour-temperature of a photoflood lamp (this type of lamp is now known as 'Movieflood') at 115 volts is $3,500^{\circ}$ K., a drop to 110 volts will lower the temperature to about $3,425^{\circ}$ K. and a rise to 120 volts will raise the lamp to $3,575^{\circ}$ K."

It was noted that the temperature of the "Movieflood lamp is $3,450^{\circ}$ K." Tungsten melts at $3,655^{\circ}$ K., so "we are not a great deal below the melting-point of tungsten."

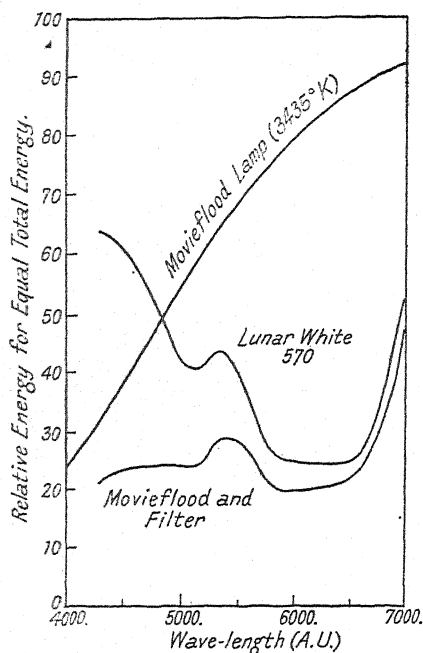


FIG. 21.

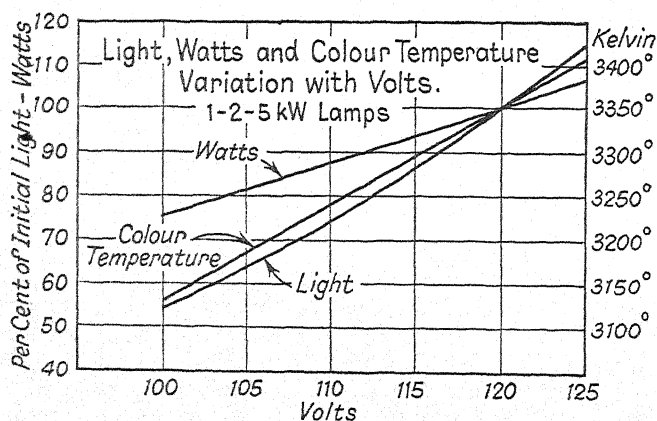


FIG. 22.—Characteristics of gas-filled tungsten lamps when operated at voltages other than their rated values. Accurate voltage control is essential in colour photography. (S.M.P.E. Studio Lighting Committee.)

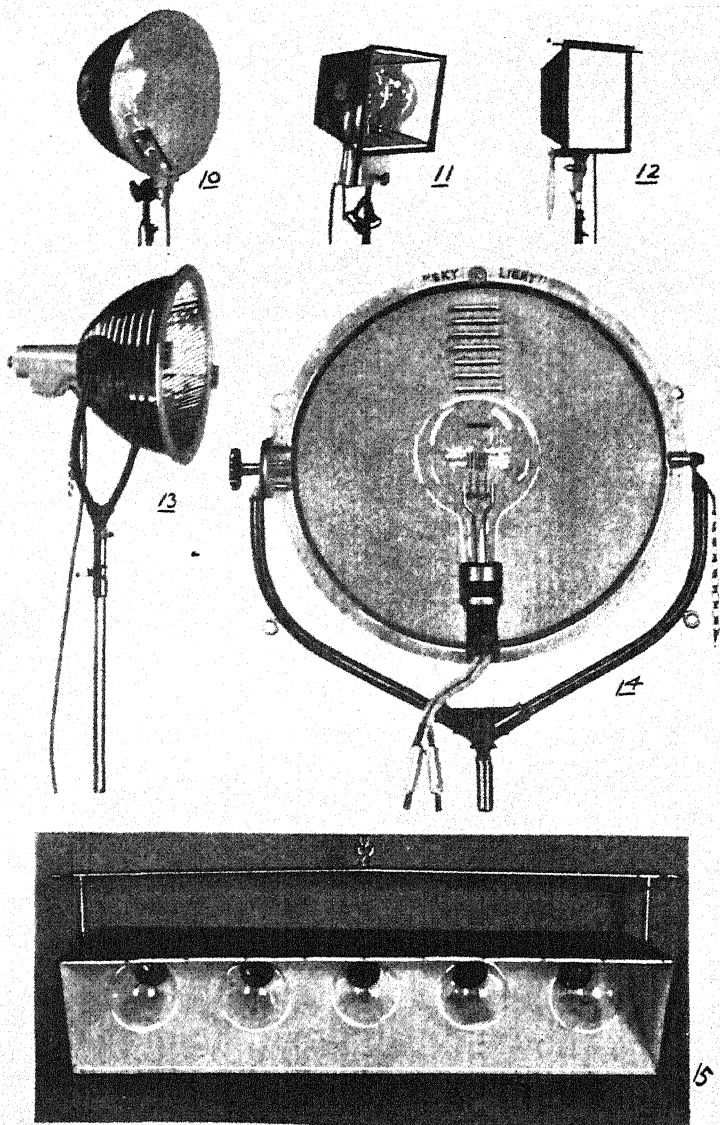


FIG. 23A.—Lamp No. 10: M-R Type 16 Cinelite. Lamp No. 11: Broadside (doubles), M-R Type 20. Lamp No. 12: Broadside (singles). Lamp No. 13: M-R Type 45 rifle lamp. Lamp No. 14: Sky light. Lamp No. 15: Overhead strip light.

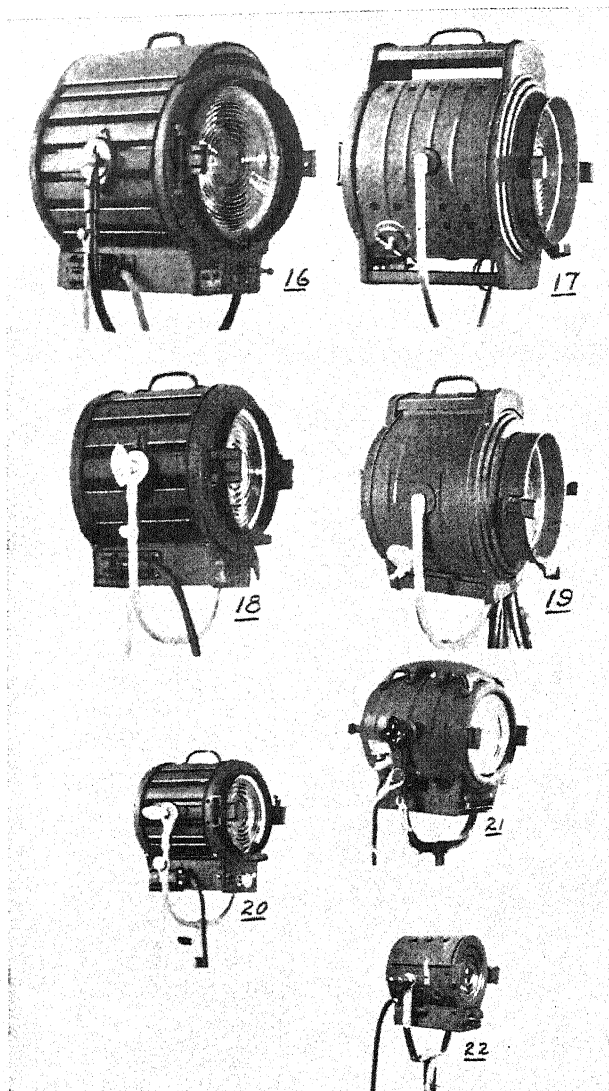


FIG. 23B.—Studio spotlamps—lens types. *Lamp No. 16:* M-R Type 414 Senior Solarspot. *Lamp No. 17:* B & M Senior. *Lamp No. 18:* M-R Type 410 Junior Solarspot. *Lamp No. 19:* B & M Junior. *Lamp No. 20:* M-R Type 406 Baby Solarspot. *Lamp No. 21:* B & M Key-Lite. *Lamp No. 22:* B & M Dinky Inky.

“ It would be worth while to use lamps in series with a very small rheostat and adjust for constant voltage in order that the blue to red ratio in the visible spectrum may not change during the course of shooting a scene.”

In America the following tungsten filament Mole-Richardson lamps are available for colour photography:

Tungsten Filament Spotlamps and Floodlamps.

Fig. 23 (A), (B), and (C) illustrate the various lamps described below.

(10)¹ *M.R. Type 16 Cinelite*.—A spun aluminium reflector, finished inside by wire brushing and chemical treatment, which gives it a diffusing characteristic; used where lightness and portability are required.

(11) *Broadside (Doubles)*.—Two flood-type reflectors housed in one unit, used for floor, side, and overhead lighting. One of the first incandescent units made.

(12) *Broadside (Singles)*.—Similar to Lamp No. 11, but accommodating only one bulb.

(13) *M.R. Type 45 Rifle Lamp*.—Stamped metal reflector, chromium plated with rifled corrugations for diffusion. Used for general floor lighting.

(14) *Sky Light*.—A shallow diffuse reflector about 24 in. in diameter. Used below and above sky backings and screens where flat, even light distribution is required.

(15) *Overhead Strip Lamp*.—A trough-like unit containing sockets for five 100-watt PS-52 bulbs. Used to supply fill-in light where it is difficult to use a more bulky housing.

(16) *M.R. Type 414 Senior Solarspot*.—A 14-in. diameter Fresnel-type lens. An Alzac spherical mirror is used at the rear of the bulb to direct the light towards the lens. Used, where high-wattage units are desirable, for back-lighting, front-lighting, and side-lighting.

(17) *B. & M. Senior*.—Similar use to Lamp No. 16.

(18) *M.R. Type 410 Junior Solarspot*.—A 10-in. diameter Fresnel-type lens. An Alzac spherical mirror is used at the rear of the bulb to direct the light toward the lens. Used for back-lighting, front-lighting, and modelling within its intensity range.

(19) *B. & M. Junior*.—Similar use to Lamp No. 18.

(20) *M.R. Type 406 Baby Solarspot*.—A 6-in. diameter Fresnel-type lens. An Alzac spherical mirror is used at the rear of the bulb to direct the light toward the lens. The small size of this lamp permits its use in places where the larger lamps cannot be accommodated, particularly where it is necessary to conceal a source of high-intensity light.

¹ Numbers refer to Mole-Richardson identification.

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(21) *B. & M. Baby Keg-Lite*.—Similar use to Lamp No. 20.

(22) *B. & M. Dinky Inky*.—An extremely small Fresnel-type lens unit accommodating 100- or 150-watt bulbs. For use where high-intensity controllable light is needed at close range from a unit which may be hidden behind a pillar, mounted on the camera dolly, or carried by an assistant.

TABLE 2.—LAMPS (TUNGSTEN FILAMENT) FOR SET LIGHTING

M.R. Lamp No.	Unit.	Degrees Beam Divergencies.*		Bulb No. (B. & W.)†	Bulb No. (Colour).
		Min.	Max.		
10	M.R. Type 16 Cinelite	60	60	12	—
11	Broadside (Doubles)	90	90	11	9
12	Broadside (Singles)	90	90	5	—
13	M.R. Type 45 Rifle Lamp	60	60	10 or 11	—
14	Sky light	180	180	2	2
15	Overhead Strip Lamp	—	—	11	—
16	M.R. Type 414 Senior Solarspot ..	10	44	2	2
17	B. & M. Senior	10	44	2	2
18	M.R. Type 410 Junior Solarspot ..	10	44	3	3
19	B. & M. Junior	10	44	3	3
20	M.R. Type 406 Baby Solarspot ..	8	40	5-6	5-6
21	B. & M. Baby Keg-Lite	8	40	5-6	5-6
22	B. & M. Dinky Inky	—	—	7 or 8	—
23	M.R. Type 226 24-in. Sunspot ..	8	44	2	2
24	M.R. Type 360 36-in. Sunspot ..	12	24	1	1
25	B. & M. Type T-5 or M.R. Lens Type Studio Spotlight	8	40	2	2

* Approximate figures referring to usable photographic light.

† For black-and-white photography.

(23) *M.R. Type 226 24-in. Sunspot*.—A 24-in. diameter glass mirror, with a spill-ring that allows only projected light to leave the lamp. Used for back-lighting large sets, in which case the heads are removed from the pedestals and are mounted on parallels or platforms built at the top of the set or hung from the stage roof or ceiling.

(24) *M.R. Type 360 36-in. Sunspot*.—A 36-in. diameter glass mirror. Used where the highest intensity of projected light is required from an incandescent tungsten source.

The Fluorescent Low-Pressure Mercury Vapour Lamp

These are very low-pressure mercury electric discharge tubes, known in Britain as Type MCF, coated on the inside with phosphors, which fluoresce mainly to radiation of 2,537 Å., of which the tube is an efficient generator.

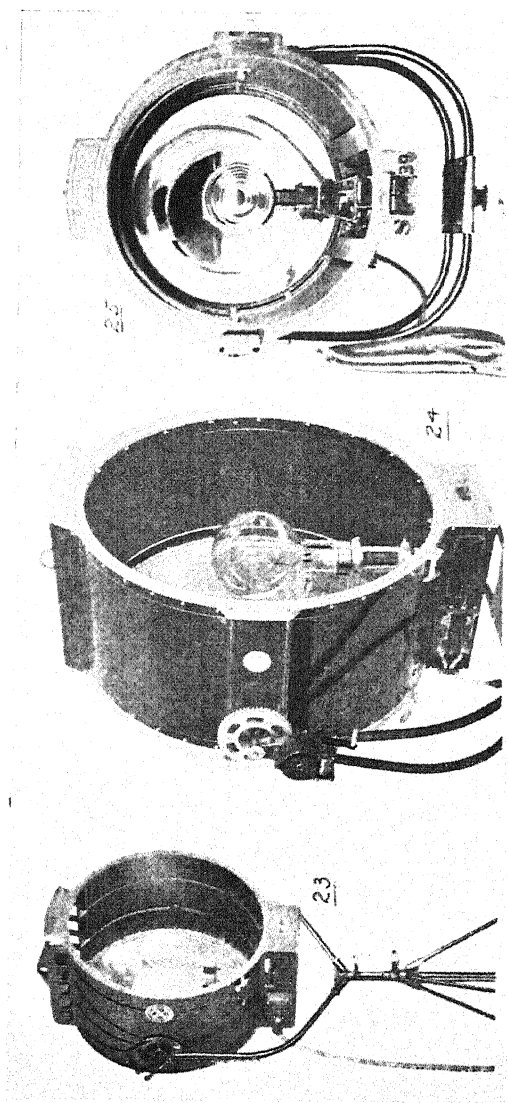


FIG. 23C.—Studio spotlights—reflector types. Lamp No. 23: M-R Type 360 36-inch Sunspot. Lamp No. 24: M-R₂ Type 360 36-inch Sunspot. Lamp No. 25: M-R Lens Type studio spotlight.

TABLE 3.—MOTION PICTURE STUDIO INCANDESCENT LAMPS FOR MODELLING LIGHT (Voltage—115 Volts or 120 Volts)
(Courtesy of General Electric Co., U.S.A.)

Bulb No.	Watts.	Bulb.	Base.	Amps.	M.P. Lamps for Black-and-White Photography			C.P. Lamps for Color Photography with Filter		
					Approx. Initial Color-Temp.	Average Initial Lumens.	Avg. Life.	Approx. Initial Color-Temp.	Average Initial Lumens.	Avg. Life.
1	10,000	G-96	Mog. Bip.	87.0	3,380° K.	327,000	75	3,380° K	327,000	75
2	5,000	T-64 or G-64	Mog. Bip.	43.5	3,380°	165,000	75	3,380°	165,000	75
3	2,000	T-48 or G-48	Mog. Bip.	17.4	3,275°	57,000	100	3,380°	65,000	25
4	1,000	G-48	Mog. Bip.	8.7	3,175°	25,500	100			
5	750	T-24	Med. Bip.	6.5	3,240°	20,000	50	3,380°	24,500	12
6	500	T-20	Med. Bip.	4.4	3,210°	13,000	50	3,380°	16,000	8
7	150	T-8	D.C. Bay.	1.3	3,060°	3,300	25			
8	100	T-8	D.C. Bay.	.9	2,975°	1,950	50			

TABLE 4.—PHOTOGRAPHIC LAMPS FOR FLOOD AND FILL LIGHTING

Bulb No.	Watts.	Description.	Bulb.	Base.	Volts.	Amps.	Approx. Initial Color-Temp.	Average Initial Lumens.	Avg. Life.
9	2,000	CP Movieflood	PS-52	Mog. Scr.	105-120	17.4	3,380° K	65,000	15
10	1,500	MP Photographic	PS-52	Mog. Scr.	115 or 120	13.1	3,180°	37,500	250
11	1,000	MP Photographic	PS-52	Mog. Scr.	115 or 120	8.7	3,130°	24,500	250
12	1,000	No. 4 Photoflood	PS-35	Mog. Scr.	105-120	8.7	3,400°	33,500	10
13	500	No. 2 Photoflood	A-25	Med. Scr.	105-120	4.4	3,400°	17,000	6
14	250	No. 1 Photoflood	A-21	Med. Scr.	105-120	2.2	3,400°	8,650	3
15	1,000	No. 4B Daylight Blue	PS-35	Mog. Scr.	105-120	8.7	4,800° X	21,800	10
16	500	No. 2B Daylight Blue	A-25	Med. Scr.	105-120	4.4	4,800° X	11,000	6
17	250	No. 1B Daylight Blue	A-21	Med. Scr.	105-120	2.2	4,800° X	5,600	3

G 2 spherical. PS=pear shaped. T=tubular. A=modified pear-shaped. Numbers refer to diameter in $\frac{1}{8}$ inch.
X Approximate; intended to supplement daylight.

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The pressure of mercury is of the order of 6-10 microns (approximately one-hundred-thousandth of an atmosphere). A range of phosphors is available giving many colour possibilities. Zinc beryllium silicate and magnesium tungstate used in different combinations give a close approximation to various phases of natural daylight. The efficiency is very high, a 40-W. tube delivering 50 lumens per watt against a Class A-1 tungsten filament lamp which is rated at 20 lumens per watt. In Britain 15-W. to 80-W. lamps are available. The characteristics of the 80-W. lamp are as follows:

Lamp wattage	..	..	..	..	80
Length of source	..	..	..	..	5 ft.
Diameter of source	..	..	..	..	1½ in.
Supply	..	..	..	..	A.C.
Supply volts	..	..	..	..	200/250 volts
Initial efficiency	..	..	..	..	35 l./w.
Lamp voltage drop	..	..	..	..	110 volts
Lamp current	..	..	..	..	0.8 amperes
Life	..	..	..	..	3,000 hours
Control gear	..	..	..	..	Choke and starting switch

In the U.S.A. a large range of tubes is available, varying from 6 watts to 100 watts, and in length from 9 in. to 8 ft. Colour-temperatures are roughly approximated of 3,500°-4,500° K. and 6,500° K., the latter being the equivalent of Illuminant C of the I.C.I. system. The rated average life of these tubes varies from 1,500 hours for the 6- and 8-W. T-5 tubes to roughly 5,000 hours for the 100-W. T-17 tube. These lamps are used in the U.S.A. on D.C. circuits by employing a series resistance in connection with a suitable induction coil and starting switch, but the efficiency must naturally be greater with normal A.C. operation. However, since the stroboscopic effect must be eliminated, it is necessary to run fluorescent tubes on D.C. circuits for motion picture photography. Large banks of these tubes are very useful in the studio as a source of generally diffused light giving the minimum of shadow.

D. Illuminants having Continuous and Discontinuous Spectra Mixed

Examples

High-Intensity Carbon Arc, Flame Arc.

High Pressure Mercury Vapour Lamps.

CARBON ARCS

Carbon arcs today in use in the motion picture industry for photography and projection, are of three types—the low intensity arc, the flame arc, and the high-intensity arc. The former will be described in another section.

Mr. W. W. Lozier of the National Carbon Co. Inc., U.S.A., has kindly supplied the following authoritative information:—

(By Courtesy of the National Carbon Co. Inc., U.S.A.)

“ The flame arc is one in which the entire arc stream is made luminescent by the presence of flame materials. A photograph is shown in Fig. 24. The electrodes differ from low intensity carbons by having a somewhat larger core containing chemical compounds capable of radiating efficiently when volatilized into the arc stream. This arc is characterized by a high luminous efficiency. The chief motion picture usage of the flame arc is for the production of general illumination in motion picture studios.”

“ The high-intensity carbon arc is one in which, in addition to the light from the incandescent crater surface, there is a significant amount of light originating in the gaseous region immediately in front of the carbon as a result of the combination of a high current density and an atmosphere rich in flame materials. The brightest portion of this arc occurs in the crater on the end of the carbon. The location of the source of radiation is shown in Fig. 25. The electrodes for this type of arc contain chemical compounds similar to those used in flame arc electrodes. The current density of high intensity arcs is generally about 500 amperes per square inch, whereas that for flame arcs is ordinarily below this value. The use of the cerium family of rare earths produces a high crater brightness and a white light. The crater brightness of commercial carbons ranges from 350 to more than 900 candles/sq. mm. and exceeds 2,000 candles/sq. mm. for experimental carbons. The color temperature of the light from the crater is in the neighbourhood of 6,000° K. The high-intensity arc is used in commercial forms with a power input of as much as 17 KW. It thus combines the properties of high source brightness, daylight color of light and very high power input and radiation output per lamp. This light source is used both for spot lamps in studio lighting and for projection of motion pictures.”

For description of lamps embodying carbon arcs see below, under “ Studio Lighting.”

HIGH-PRESSURE GASEOUS DISCHARGE LAMPS

In high-pressure mercury lamps a gas such as neon or argon at a pressure of a few centimetres of mercury is used to initiate the discharge between the cathodes, which are raised to a temperature at which they act as thermionic sources. Owing to the high energy input the mercury becomes vaporized, the pressure increases to 1 atmosphere or even higher, depending upon the design of lamp and operating conditions, and the spectrum exhibits only those lines that are characteristic of mercury along with a certain amount of continuous radiation.

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When an electron possessing the velocity corresponding to an acceleration through 4.9 volts collides with a mercury atom, the latter is excited to a higher energy state, and when the system passes spontaneously from this higher state to the normal, monochromatic radiation is emitted in accordance with the relation

$$h\nu = Ve,$$

where ν is the frequency of the radiation and h is a universal constant (known as the quantum constant).¹ The corresponding wavelength is given by the relation

$$\nu = c/\lambda,$$

where c is the velocity of light, and λ is the wavelength of the radiation in cm.

In the case of mercury the first excited state of the atom gives rise to a resonance line of ultra-violet ($\lambda = 2,537 \text{ \AA}$). These invisible radiations are absorbed by the atom and are known as resonance lines.² In order to obtain visible light from mercury it is necessary to excite the mercury atom to about 6.7 volts or higher, and the whole spectrum appears only when the electron velocities exceed that corresponding to 10.4 volts.

The various designs of the high-pressure discharge lamp may be divided into two categories:

- (1) those operating at 1 atmosphere and utilizing glass envelopes, and
- (2) those operating at higher pressures and requiring the use of quartz envelopes.

In the former lamps the temperature of the inner glass wall is about 350°C ., the pressure of mercury 1 atmosphere, and the initial efficiency 40 lumens per watt. The average brightness of the light-source itself is about 30 candles per sq. cm. These lamps radiate very little more than the normal mercury spectrum. They are useless for studio illumination unless balanced with suitable tungsten sources to compensate for the absence of red light. Even mixture and distribution have proved a very difficult problem.

Recently the British Thomson-Houston Company have perfected an extremely important type of high-pressure electric discharge lamp in which the deficiency of red in the earlier types is made good by the introduction of cadmium. Low-pressure cadmium mercury lamps have been available for some years, and they have been used with conspicuous success for the printing of Dufaycolor film. A lamp working at a few atmospheres was produced in America before the

¹ h = Planck's constant = 6.55×10^{-27} erg. sec.

² Resonance radiation is the radiation produced by transitions from the lowest excited state to the normal state.

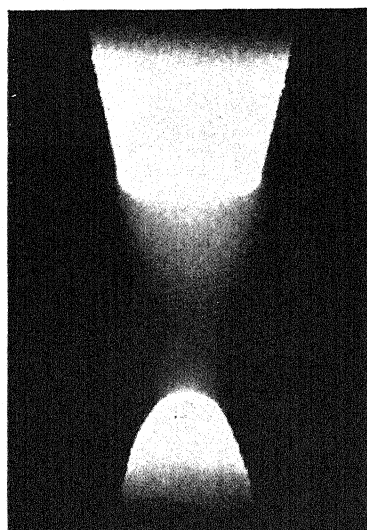
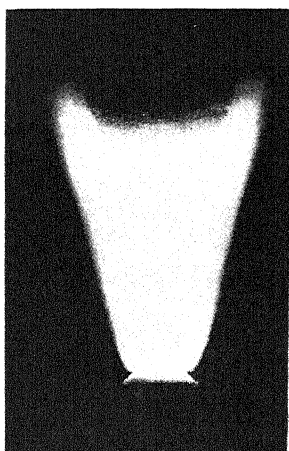


FIG. 24.—Flame type carbon arc discharge.

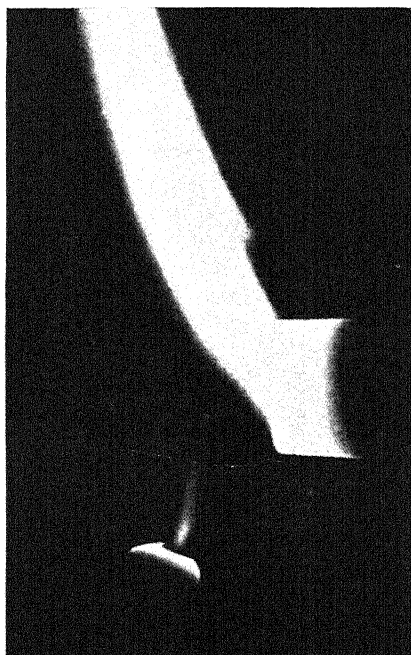


FIG. 25.—D.C. high intensity carbon arc with rotating positive carbon.

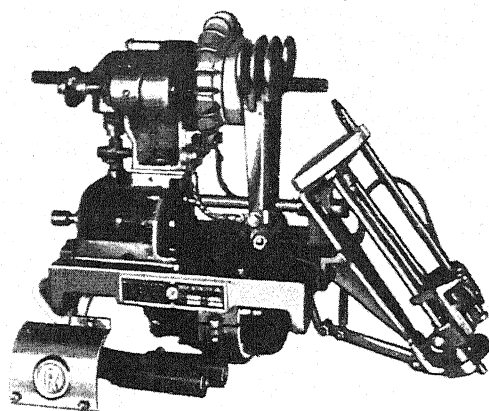


FIG. 26.—H.I. Arc rotating element.

war, but the true high-pressure lamp presented peculiar problems which have only very recently been solved. The new lamp belongs to a type now known as "Compact Source," and the British Thomson-Houston series is identified as Type ME. This is an air-cooled lamp and consists of a strong quartz bulb with walls several millimetres thick, approximately spherical in shape, into which are sealed two solid cylinders of tungsten, known as the main electrodes, which are supported on tungsten shanks. On each of these shanks is wound a spiral of tungsten wire, coated with an emitting material, which is known as

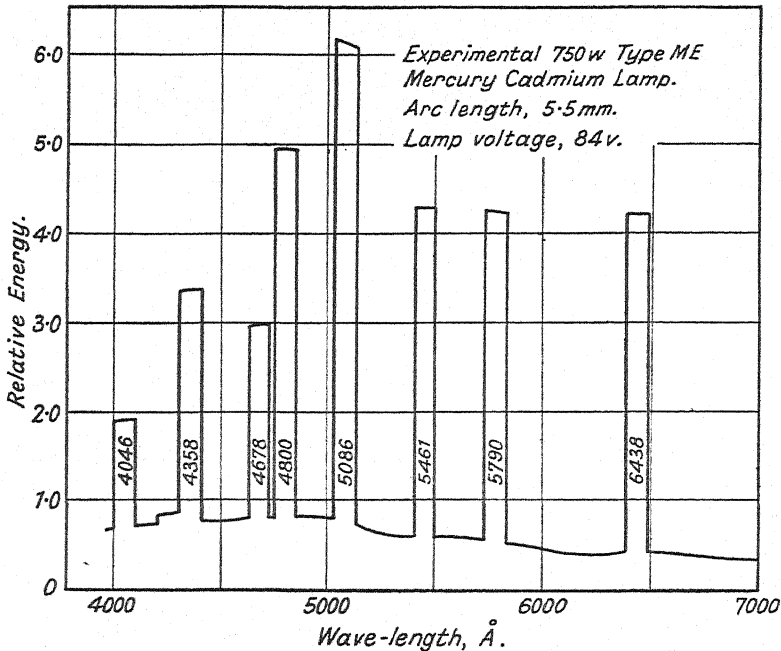


FIG. 27.—Spectral energy distribution of the 750 W. Type ME Mercury Cadmium Discharge Lamp.

the starting electrode. An auxiliary electrode of bare tungsten wire is sealed into the bulb with its end adjacent to one of the starting electrodes and spaced about 1 mm. from it, and connected through a high resistance outside the bulb to the other terminal of the lamp. The arc gap measured between the two main electrodes is approximately 5-10 mm. The bulb contains a filling of gas at a low pressure. The current is led into the main electrodes through molybdenum-foil strips which make a vacuum-tight seal in the quartz. This has proved a difficult task, but seals capable of carrying no less than

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several hundred amperes into electrodes in a quartz bulb have now been made.

Lamps rated at 2.5 KW. and above have been used for the photography of colour films in the studio, and the balance of the separation negatives is practically identical to that obtained with the usual high-intensity arcs. It will be observed from the spectral distribution of energy (Fig. 27) that the cadmium vapour is responsible for a strong emission at the wavelength 6,438 Å. This emission is at a useful position in the red region, since the transmittances of red and green filters do not overlap here. This is true of additive processes, such as Dufaycolor, besides those processes in which separate films are employed, such as Technicolor.

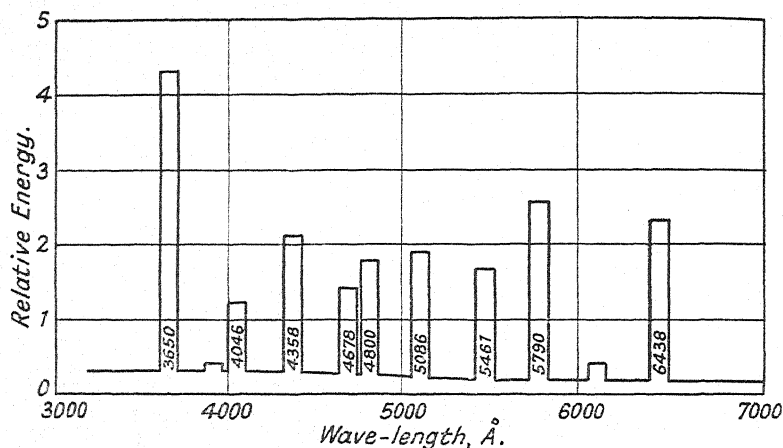


FIG. 27A.—Spectral distribution of radiation after cadmium has been added to the mercury arc lamp.

A previous defect of lamps of this type was that the maximum emission took several minutes to be attained. In fact, the lamp had to warm up until all the mercury had vaporized. This would be a nuisance in the studio, but the disadvantage has been eliminated by operating the lamp in an oven, so that the mercury is kept vaporized and the arc is ignited whenever required by applying a high-voltage impulse to the lamp. Full light can then be obtained with virtually no delay.

The high-pressure cadmium mercury lamp will operate from supplies down to 110 volts, and will operate on D.C. or A.C. Special design is used for D.C. in the larger sizes.

The range of lamps now available in England of this type is 250, 500, and 1,000 watts, and experimental lamps have been made in 5-

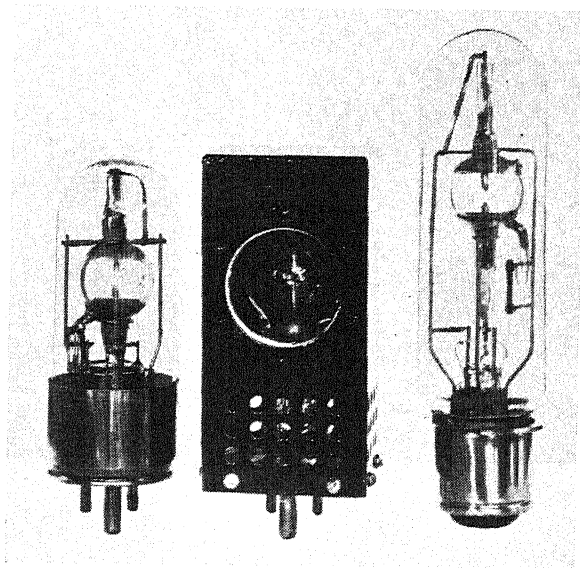


FIG. 28.—Three forms of 250-watt Compact Source Lamp.
(By courtesy of the British Thomson-Houston Co. Ltd.)

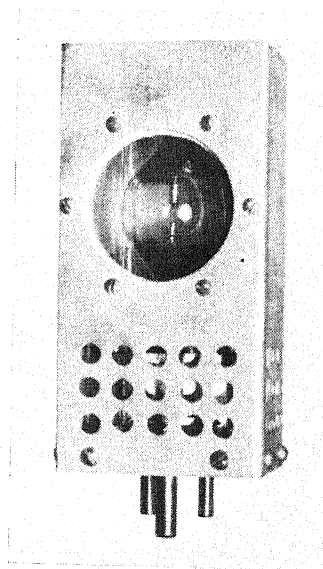


FIG. 28A.—250-watt Type ME Compact Source Box Lamp.
(By courtesy of the British Thomson-Houston Co. Ltd.)

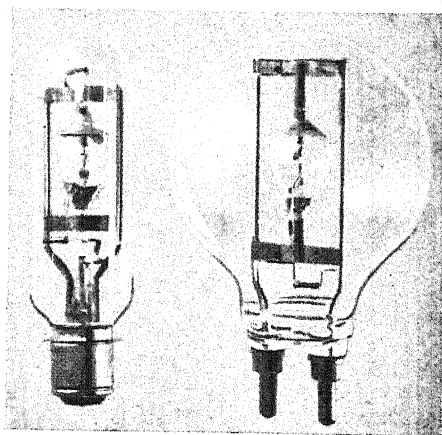


FIG. 28B.—500-watt Mazda Type ME air-cooled lamps.

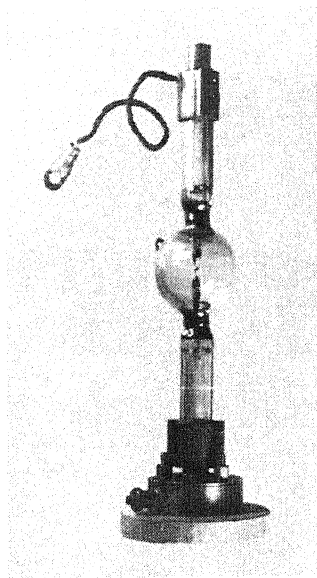


FIG. 28C.—1,000-watt Type ME Compact Source Lamp.

(By courtesy of the British Thomson-Houston Co. Ltd.)

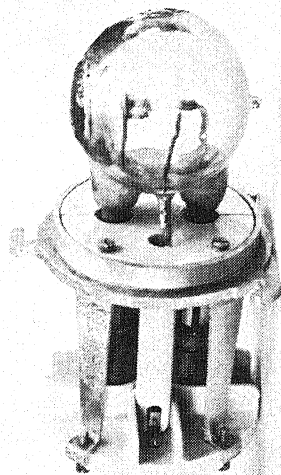


FIG. 28D.—5-Kw. Type ME Single-ended Compact Source Lamp.

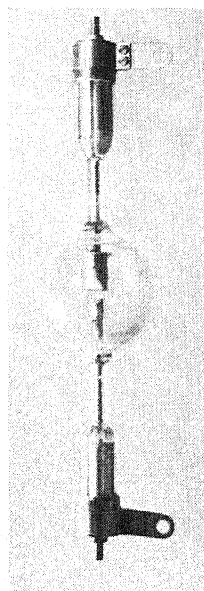


FIG. 28E.—10-Kw. Double-ended Compact Source Lamp.

(By Courtesy of the British Thomson-Houston Co. Ltd.)

(Facing p. 67)

THE THEORETICAL BASIS

10-, and 20-KW. sizes. The high-power lamps use no outer glass envelope, and they may be either single- or double-ended in construction. (Figs. 28 A, B, C, D, E.)

TABLE 5.—CHARACTERISTICS OF COMPACT SOURCE MERCURY VAPOUR LAMPS

(*Courtesy British Thomson-Houston Co., Ltd.*)

Rating of lamp	250	500	1,000	5,000 *	10,000 * watts
Current (approx.)	4.1	8.4	16.6	72	150 A.
Voltage drop	60-75	60-75	60-75	60-80	60-80 volts
Supply voltage†	200/250	200/250	200/250	200/250	200/250 volts
Arc length	3.75	5	5.5	10	10 mm.
Approx. arc width	1.5	2	2.5	7.5	10 mm.
Max. brightness initial ..	20,000	20,000	35,000	45,000	80,000 c. per sq. cm
Luminous efficiency (ap- prox.)	40-45	40-45	45	50	50 l. per w.
Overall length	130	240	245	340	450 mm.
Diameter of outer bulb ..	64 × 55	65	45‡	85-90‡	110‡ mm.

* Experimental lamps.

† Supply A.C. or D.C. (special lamps for D.C. in ratings above 1,000 watts). Will operate on 110-volt supply with special starting circuit.

‡ No outer jacket in lamps of 1,000 watts and above.

The brightness at the centre of the arc ranges from 10,000 to 100,000 candles per sq. cm., depending upon the arc length and the wattage of the lamp, and the efficiency is between 45 and 50 lumens per watt.

The light output is more constant than a carbon arc, and fluctuations in the voltage of the supply cause smaller variations in the light output than in the case of a tungsten lamp. For example, a 10 per cent. rise in mains voltage increases the light output by 20 per cent. in the case of the ME lamp and by 36 per cent. with a tungsten filament projector lamp.

There can be no doubt that this beautiful lamp will play a most important part in the future of studio illumination for colour photography. The steadiness of spectral quality and quantity of the light emitted will recommend it strongly to directors who have suffered from arc troubles in the past. Furthermore, there is bound to be a considerable saving in studio personnel, since there does not seem to be any reason why one man should not operate a large number of lamps.¹

It has been demonstrated that both Technicolor and Dufaychrome colour balance and rendering are hardly distinguishable from those obtained with the standard high-intensity arcs corrected with Y-filters.

¹ A full range of complete studio units is now available in England, from Mole-Richardson, Ltd.

STUDIO ILLUMINATION

Twenty years of research and development lie behind the efficient lamps which today are ready in the studio to obey the imaginative faculty of a lighting artist. The instrumental means which the artist employs in the case of the motion picture are of extraordinary complexity and refinement, but while it is true that within the province of art the creator of the *means* is unlikely to receive a glory equal to that bestowed upon the creator of the *end* which it is the object of the means to attain, we technicians have our own roll of honour and high upon that list stands the name of Mole-Richardson. This famous partnership originated in 1927, when Peter Mole joined E. C. Richardson and set up their business in a garage on Santa Monica Boulevard in Hollywood. They developed the first complete range of high-wattage units which represented a revolutionary change in lighting technique. There were "Broads, Low Broad-sides, Hi-low Broad-sides, Bunchlights, Rifles, 18-inch Sun Spots, and 24-inch Sun Spots" and other famous types.

The advent of sound led to fundamental alterations in design in order to eliminate sound originating in expanding metal or bolts and nuts adjusting themselves to temperature gradients.

But it was Technicolor acting as taskmaster which forced Mole-Richardson to turn back to the discarded arc as the only practicable source to satisfy the greed (at that time) of colour photography for "light, more light."

We are told that in 1933, Technicolor requested Mole-Richardson to investigate the possibility of developing a motion picture arc lamp for use as a general lighting unit. The specifications they submitted were:

1. The lamp should produce an illumination level of 200 foot-candles, as measured at fifteen feet with a standard Weston photometer.
2. It must have a comparatively flat distribution curve over a projection angle of sixty degrees or more, and the field of illumination should be devoid of any hot spots, *i.e.*, areas of illumination that are photographically objectionable.
3. The feeding mechanism of the lamp should be so designed as to provide a reasonable uniform level of light intensity during its period of operation, and the spectrum of the light emitted should not show any alteration of its characteristics during the period of operation.
4. It should be silent in operation, so that it may be satisfactorily operated in conjunction with modern sound recording apparatus.
5. It should take such a form, and be so mounted, that it will be convenient for placement, and be of such weight as to be easily handled on the set.

THE THEORETICAL BASIS

- It should be economical in operation with regard to attendance, the consumption of current, and carbon electrodes.

With the assistance of the National Carbon Company in the design of specially cored carbons and with a new approach to control of gap, a

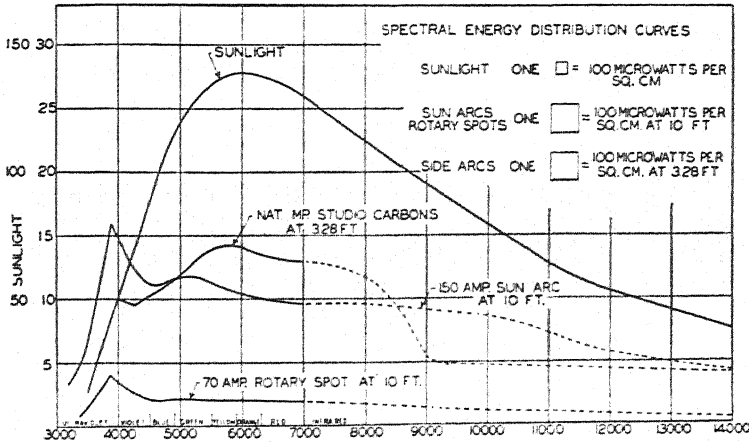


FIG. 29.—Spectral characteristics of various types of arcs (F. T. Bowditch and A. C. Downes, *Journ. Soc. Mot. Pic. Eng.*, 25, No. 5, Nov. 1935).

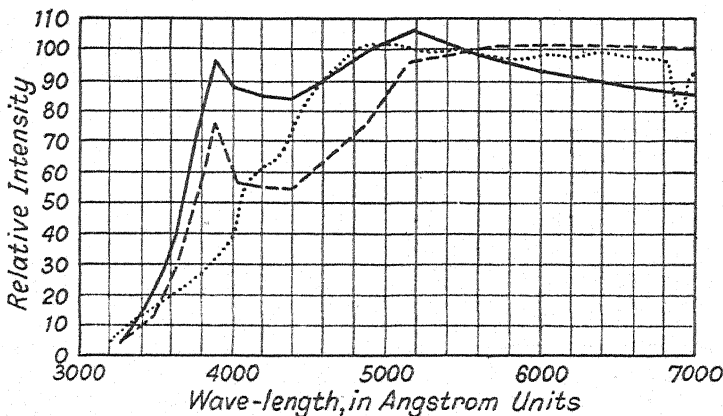


FIG. 30.—Solid line: Spectral energy distribution, 13.6 mm. H.I. carbon arc at 63 volts, 115 amp.—through glass. Dashed line: Same, through glass and Y-1 filter. Dotted line: Solar radiation at sea level.

great improvement was effected. These lamps housed the "White Flame" arc in which the major proportion of the light flux is derived from the incandescent particles of the rare earths such as cerium streaming out in a flame from the large cores of the carbons. The

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flame is the source of light rather than the intensely hot tips of the carbons. At first Mole-Richardson produced a Twin Broadside and an

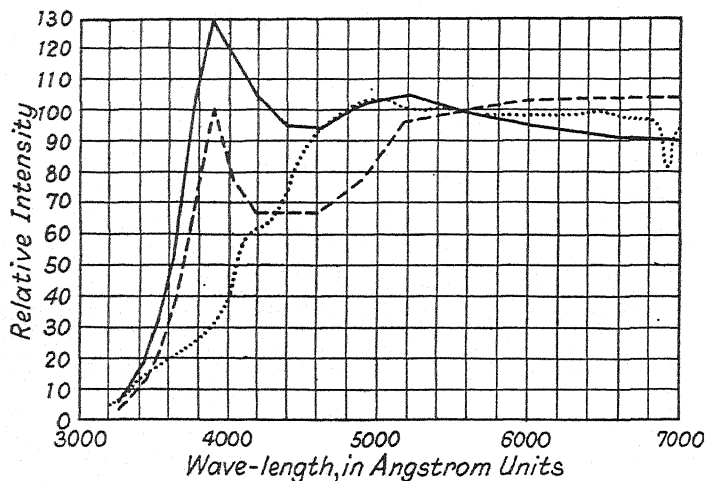


FIG. 30A.—*Solid line*: Spectral energy distribution, 9 mm. H.I. carbon arc at 49 volts, 70 amp.—through glass. *Dashed line*: Same through glass and Y-1 filter. *Dotted line*: Solar radiation at sea level.

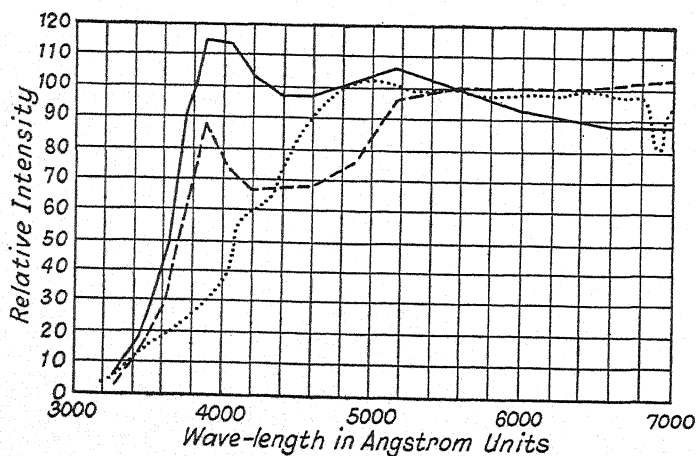


FIG. 30B.—*Solid line*: Spectral energy distribution, 16 mm. H.I. carbon arc at 81 volts, 150 amp.—through glass. *Dashed line*: Same, through glass and Y-1 filter. *Dotted line*: Solar radiation at sea level.

overhead Scoop, and then they embarked on an investigation which resulted in the first application on the so-called "High-Intensity" searchlight arc.

The high-intensity arc was developed to meet the requirements of optical projection which demand a small symmetrically-shaped source of the maximum intensity. The source, if it was to be the crater of an arc, had to be unobstructed by the negative carbon, which was eventually placed at an angle of 127° to the positive. To obtain even emission it was found necessary to rotate the positive carbon and to feed it forward mechanically. (The rotation must be in excess of 10 r.p.m.) The passage of the flow of electrons from the negative carbon on their way to the core of the positive *through* the volatilized particles of the flame issuing from the positive, superheats these in the ensuing bombardment and thus there is built up the tremendous temperature of from 9,440-11,240° F. This state of affairs is present

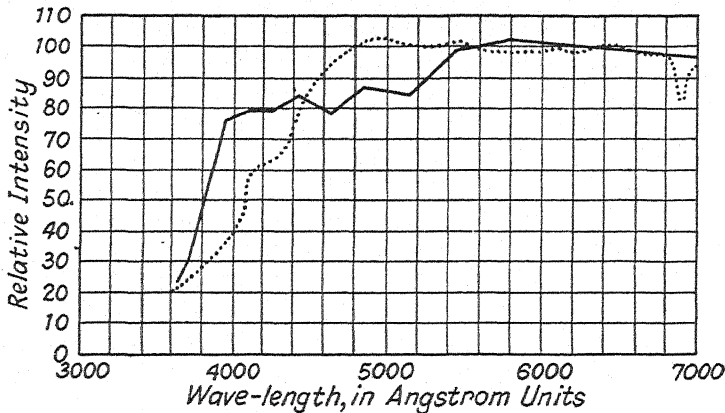


FIG. 31.—Solid line: Spectral energy distribution, 8 mm.-7 mm. MP studio carbons at 37 volts, 40 amp. Dotted line: Solar radiation at sea level. (Linderman, Handley and Rodgers, *Journ. Soc. Mot. Pic. Eng.*, June 1943.)

not far from the bottom of the crater of the positive. Since the true temperature is equivalent to that of the exterior of the sun the spectral distribution of energy is similar (Figs. 29, 30, 30A, 30B, 31) and so is its colour temperature (although not identical owing to the spectrum of the emission of a carbon arc not corresponding exactly with that of a theoretically perfect radiator). However, it is quite near enough for the purposes of colour photography and we may regard the radiation of a high-intensity arc as approaching very closely that of sunlight in all respects. Actually the bombarded rare earths emit too much deep blue and ultra-violet and these radiations have to be eliminated by use of a pale yellow (minus blue and violet) filter, which is always used with the H.I. arcs.

Originally the H.I. arcs were available in two sizes, the M-R Type 90, operating at 120 amperes and the M-R Type 170, operating at 150

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amperes. Today these units are known as the "Molarc" and the latest addition to the range, namely M-R Type 450, is an immensely powerful lamp operating at 225 amperes.

These H.I. lamps have been the principal source of light for Technicolor productions, and it is hardly practicable to undertake any serious production in a studio unequipped with an adequate range of Molarcs.

Difficulties were experienced with the light distribution given by

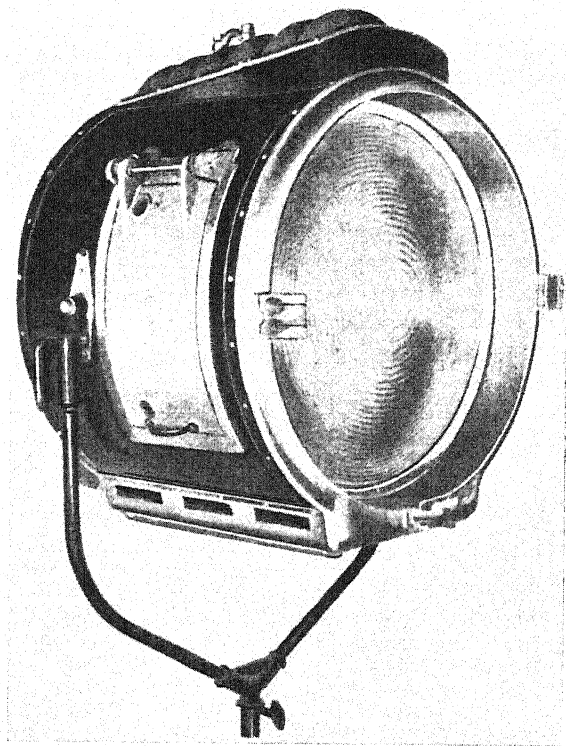


FIG. 32.—M-R Type 450 Arc Spotlamp.

spotlamps in the early days: parabolic mirrors gave dark spots when flooded and normal condenser lenses were unsatisfactory for many reasons. The problem of even distribution was solved by combining a large mirror with a *Fresnel* type plano-convex lens, originally invented by the French physicist, Augustine Jean Fresnel, for lighthouses. In a lens of this kind a series of concentric facets are cut into the convex face of a plano-convex lens. It can be made very large in diameter, yet of short focal length and nevertheless *thin* in section (Figs. 34-35).

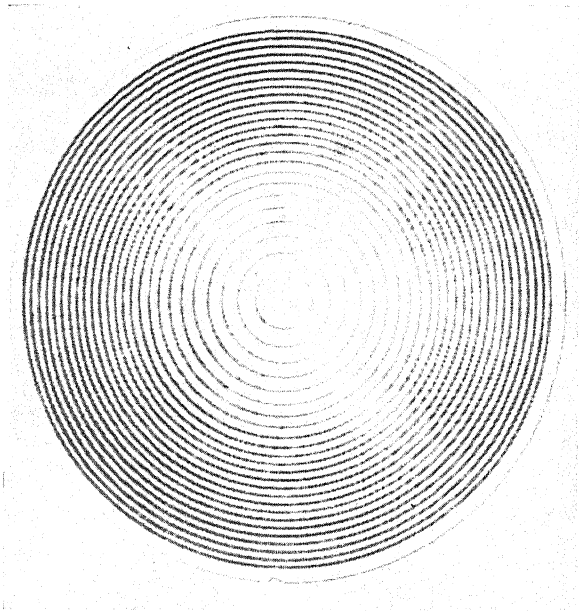


FIG. 34.—Front view of a Fresnel type plano-convex lens as used in Mole-Richardson Spotlamps. This innovation revolutionized spotlighting equipment.

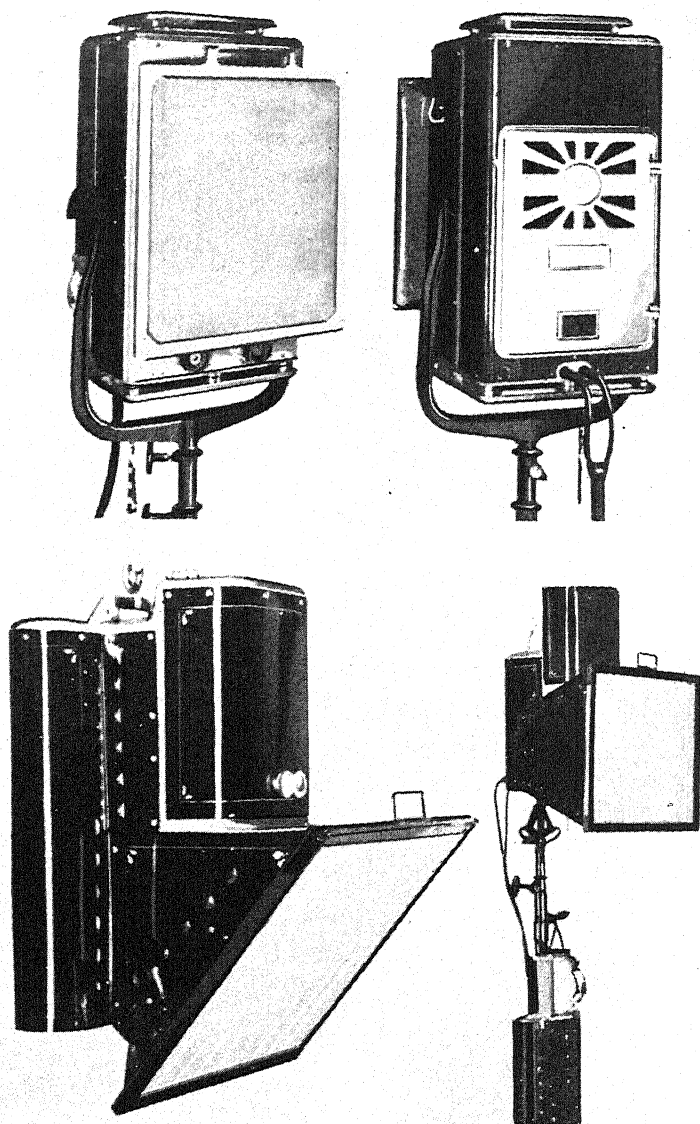


FIG. 36.—M.-R. Duarc Broadside, M.-R. Type 27 Scoop and M.-R. 29 Broadside.

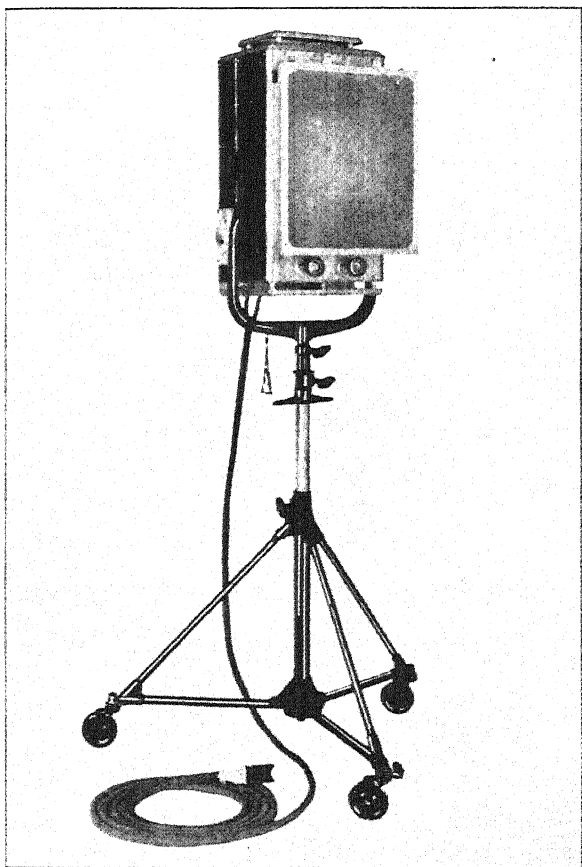


Fig. 36A.—M.-R. Duarc Type 40.

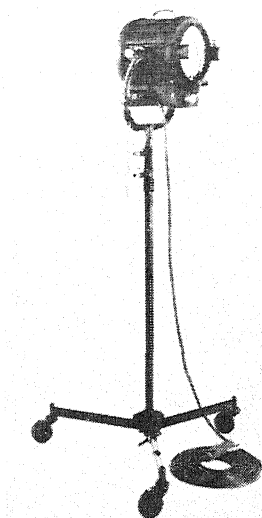


FIG. 36B.—500-watt Junior Solarspot Lamp. M.-R. Type 406.

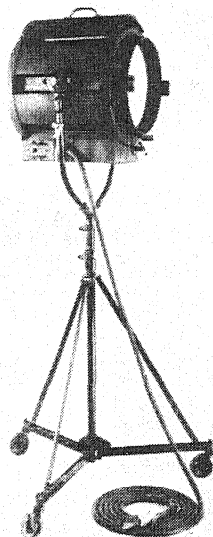


FIG. 36C.—5-Kw. Senior Solarspot Lamp. M.-R. Type 414.

(By courtesy of Mole-Richardson (England) Ltd.)

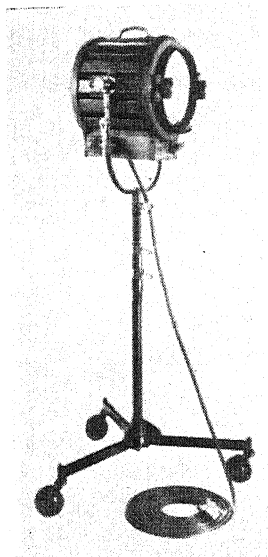


FIG. 36D.—2,000-watt Junior Solarspot Lamp. M.-R. Type 410.

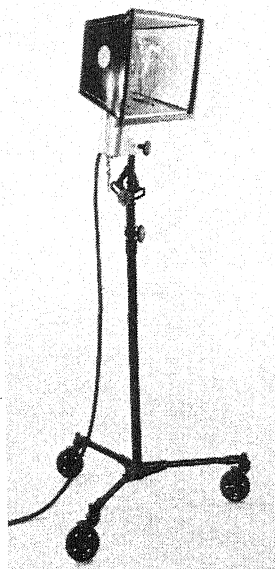


FIG. 36E.—M.-R. 1,000-watt Double Light Broad-side Lamp.

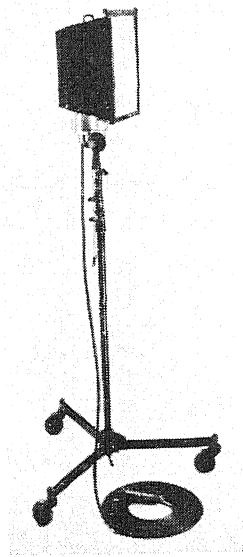


FIG. 36F.—M.-R. 1,000-watt Single Light Broad-side Lamp.

(By courtesy of Mole-Richardson (England) Ltd.)

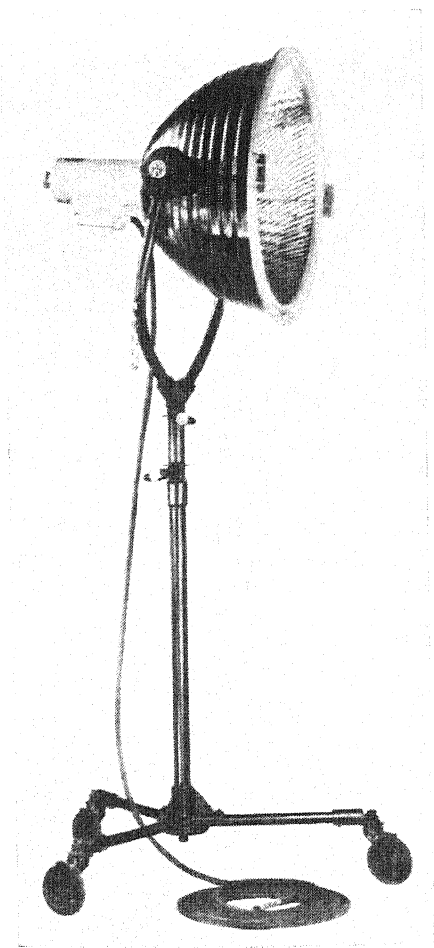


FIG. 36G.—M.-R. Type 45 Rifle Lamp.
(By courtesy of Mole-Richardson (England) Ltd.)

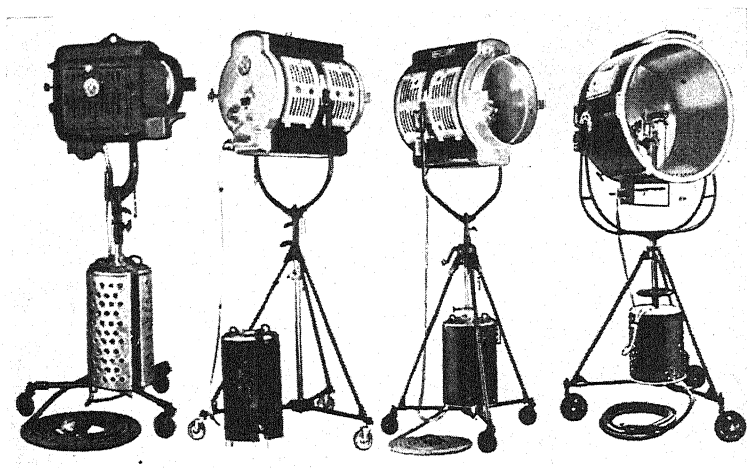


FIG. 37.—M.-R. Spotlamps 4-7.

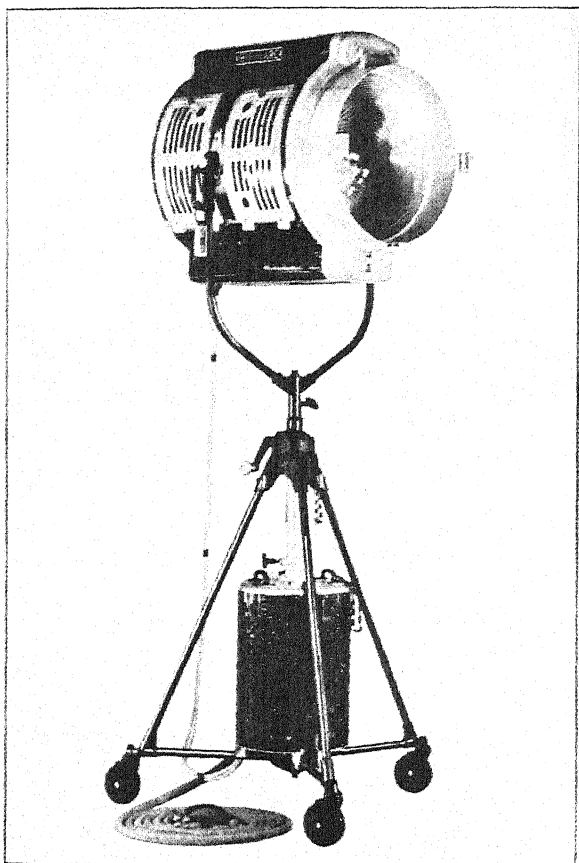


FIG. 38.—Ultra H.I. Mole-Richardson Arc Spotlamp, Type 170. Current: 115 volts; 145-150 amperes; D.C.

Designed originally to meet the requirements of photographing coloured motion pictures, these lamps have found extensive use in both that field and in lighting for normal motion-picture photography. Operating quietly so that they may be used in close proximity to a microphone, they have such illuminating capacity that they are tending to displace 36" Sun arcs. They are applicable for back lighting, cross lighting, key lighting, for wide and narrow angle front lighting, for effect lighting, and for all photographic illumination demanding a light of high brilliance, constant spectrum quality, and uniform density.

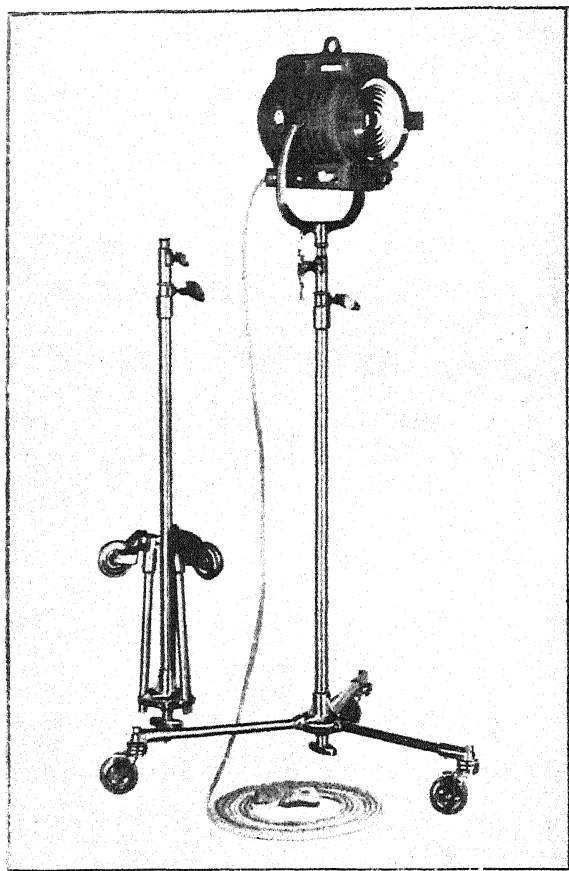


FIG. 39.—500-watt Mole-Richardson “Baby” Solarspot, Type 206, with tripod open and folded.

In both still and motion-picture photography there are many occasions where smaller light-projecting units best serve the photographer. These have a wide range of beam control. They can be spotted down to an 8° divergence and flooded to a 40° divergence with an excellent photographic field suitable for modelling, back lighting, front and cross lighting. The small size of these 500-watt lamps permits their use in spaces which cannot accommodate the larger units, and in motion-picture work in particular, permits their concealment within the motion-picture set when this is advantageous.

Richardson said in 1936: "In the motion picture industry it is seldom necessary to project a spot beam narrower than 10 degrees, which provides a spot of light about eight feet in diameter at a distance of 50 feet. It is, however, desirable to be able to flood a lamp to a divergence as great as 40 degrees, provided that the projected beam at this wide angle is of sufficient intensity to be of photographic use."

And further: "For the conditions under which spotlamps are used, it is desirable that the beam have its highest intensity at the centre and that the edges be soft, so as to permit overlapping the beams of several lamps without building up high intensities in the areas overlapped." He was describing the M-R Type 210 Junior Solarspot using a G-48 C. 13 pipost Mazda globe.

To-day all the Mole-Richardson spotlamps employ this principle of light projection.

W. W. Lozier, of the National Carbon Co. Inc., U.S.A., states: "The lighting of motion picture studios for motion picture photography can be classified into three types of application: general lighting, modeling lighting and background projection or special effects lighting. General lighting is a term used to describe the flat, diffused illumination used on the set. It renders the set photographically visible, illuminates shadows and is the counterpart of sky light. Modeling lighting or key lighting are terms used to describe that illumination which is highly directional and is used to create high lights and contrasts. It is the counterpart of sunlight. Background projection or process projection are terms which are generally used to describe that illumination which is highly directional and is used to create high lights and contrasts. It is the counterpart of sunlight. Background projection or process projection are terms which are generally used to describe the practice of projecting a background on a translucent screen at the rear of a set, to accompany the live action on the set."

"Modeling lighting levels for Technicolor, for example, range from 250 to 900 ft. candles. General illumination is usually only $\frac{1}{2}$ to $\frac{1}{4}$ as great. Screen intensities required with rear projection depend on the transmission characteristics of the screen but must be maintained high enough to blend with the foreground action."

Table 6 shows the characteristics of the most common carbon arc lamps used for motion picture set lighting. The first three lamps listed are examples of units used for general illumination. The type 40 M-R broadside lamp is an improved version which is superseding the other two. The optical system consists of a metal reflector plus diffusing glass. In each of these units two arcs are employed side by side connected in series. M-R 40 lamp is shown in Figs. 36 and 36A.

Lamps Nos. 4 to 7 are examples of modern spotlamps (Fig. 37). All of these employ a Fresnel type glass lens which provides a well-controlled beam. By means of a simple adjustment the beam spread

TABLE 6.—CARBON ARC LAMPS FOR MOTION PICTURE SET LIGHTING
(By courtesy of the National Carbon Company, Inc., U.S.A.)

Lamp No.	Unit	Degrees* Beam Divergences		Positive† Carbon No.	Negative Carbon No.	Type of Optical System.
1	M-R 27 scoop	90	90	1	6	Metal reflector plus diffusing glass
2	M-R 29 broadside	90	90	1	6	Metal reflector plus diffusing glass
3	M-R 40 broadside	90	90	1	7	Metal reflector plus diffusing glass
4	M-R 65 spotlight	8	44	2	11	Fresnel lens
5	M-R 90 spotlight	8	44	3	8	Fresnel lens
6	M-R 170 spotlight	8	48	4	9	Fresnel lens
7	M-R 450 spotlight	12	48	5	10	Fresnel lens
8	24-inch sun arc	10	24	4	12	Glass reflector
9	36-inch sun arc	10	32	4	12	Glass reflector

* Approximate figures referring to usable photographic light.

† See Table 7.

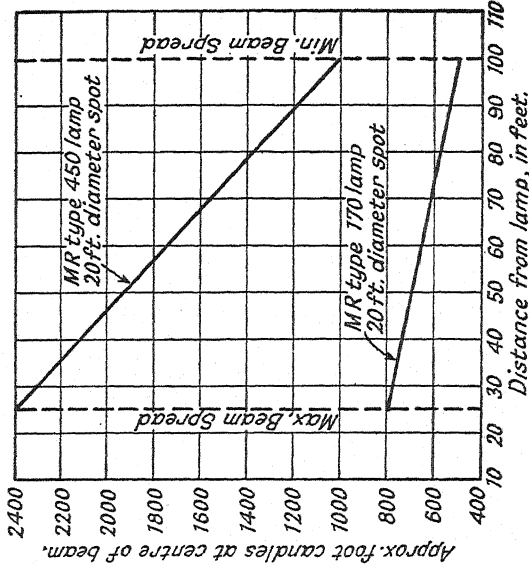
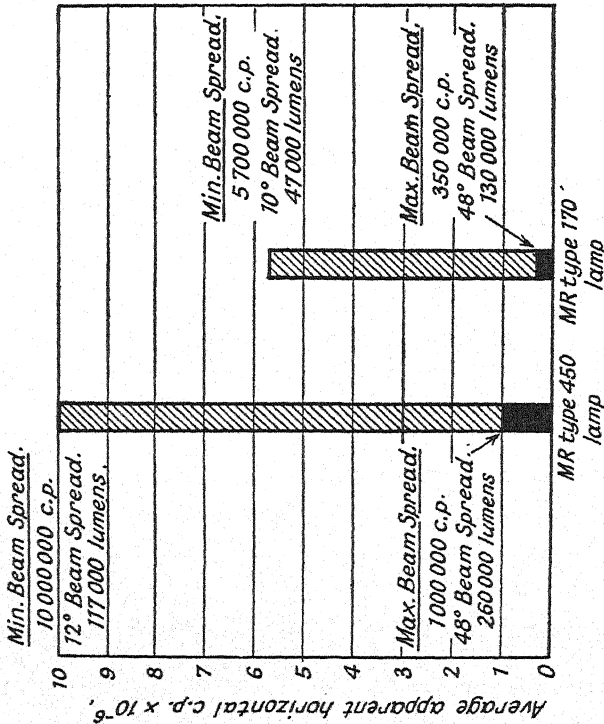


Fig. 33 (left).—Chart indicating relative illumination characteristics of MR-type 450 lamp burning the 16 mm. super H.I. studio positive at 225 amperes, and the MR-type 170 lamp burning the 16 mm. H.I. studio positive at 150 amperes.

Fig. 33 (right).—Typical curves showing illumination at centre of 20-foot diameter* spot at various distances from MR type 450 lamp burning the 16 mm. super H.I. studio positive at 225 amperes, and MR type 170 lamp burning the 16 mm. H.I. studio positive at 150 amperes.

* The diameter of the spot is defined as the diameter at which the illumination is 10% of the maximum illumination present at the centre of the spot.

COLOUR CINEMATOGRAPHY

can be varied from a small spot to a wide flood. The carbons and operating conditions employed for these different lamps are shown in

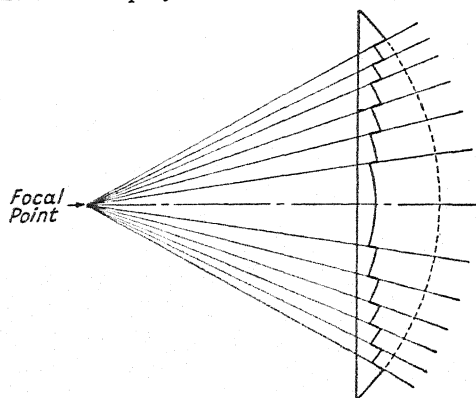


FIG. 35.

Table 6. The Type 170 lamp is shown in Fig. 38. Lamps Nos. 8 and 9 are examples of earlier types of units employing a parabolic mirror

TABLE 7.—CARBONS FOR SET LIGHTING LAMPS.
(By courtesy of the National Carbon Company, Inc., U.S.A.)

Carbon No.	Positive Carbons.	Amperes.*	Arc Volts.
1	8 mm. × 12 inch C.C. MP Studio	38-43	35-40
2	9 mm. × 20 inch H.I. Projector	65-70	52-54
3	13.6 mm. × 22 inch H.I. Studio	110-115	54-56
4	16 mm. × 20 inch H.I. Studio	140-150	64-67
5	16 mm. × 22 inch Super H.I. Studio	215-225	72-75
	<i>Negative Carbons.</i>		
6	8 mm. × 12 inch C.C. MP Studio		
7	7 mm. × 9 inch C.C. MP Studio Negative		
8	$\frac{7}{16}$ × 8 inch C.C. MP Studio Negative		
9	$\frac{1}{2}$ × 8 inch C.C. MP Studio Negative		
10	$\frac{17}{32}$ × 9 inch Heavy Duty Orotip Negative		
11	7 mm. × 9 inch Suprex Negative		
12	11 mm. × 10 inch plain MP Studio Negative		

* As used in set lighting lamps.

which are still used where it is desired to project narrow beams of very great penetrating power. The Type 65 spotlamps are being replaced in most cases by the more modern and efficient Types 90, 170 and 450 lamps. The candlepower distribution for various adjustments of beam

divergences are shown in Figs. 39A-G for three spotlamps and one broadside lamp.

Typical spectral energy distribution curves of the radiation on the set are shown in Fig. 40. The curve for the Type 170 lamp is typical of the radiation from carbon arc spotlamps using the high-intensity arc. The slight excess radiation at the blue end of spectrum is removed when photographing Technicolor by the use of a light straw Brigham gelatine Y-1 filter (Fig. 41). The effect of this on the spectral energy distribution is also shown on Fig. 40. The energy distribution for the

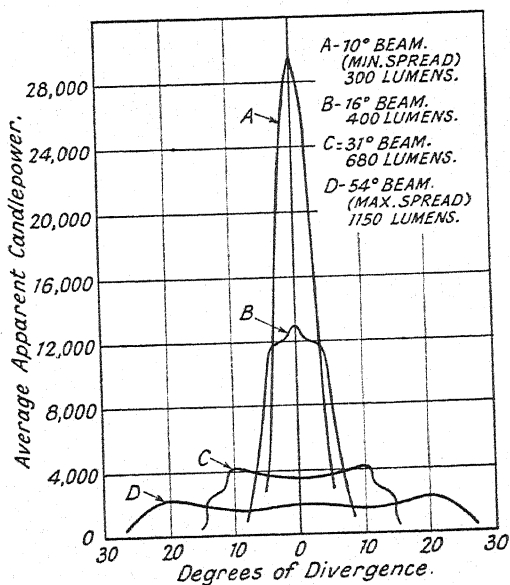


FIG. 39A.—Candlepower distribution from a Mole-Richardson "midget" spot lamp type 404, with a 200-watt, T-10 bulb d-c a bayonet base lamp.

Type 40 broadside lamp shows that this radiation can be used without modification for Technicolor to blend with the filtered spotlamp. Both of these can be mixed with daylight.

The power sources employed with carbon arc lamps used in studio photography are generally special direct current motor generators delivering approximately 120 volts across the two legs of a 3-wire distribution system. These are generally equipped with filter circuits to remove the commutator ripple which would otherwise produce an undesirable noise on the set when burning the arc.

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Terms used in Studio Lighting Practice

The terms applied to the various units of motion picture studio lighting equipment are legion and vary from studio to studio, and even from month to month. Sometimes a lamp is described by its type number alone; or by the rated current, in the case of arc spot-

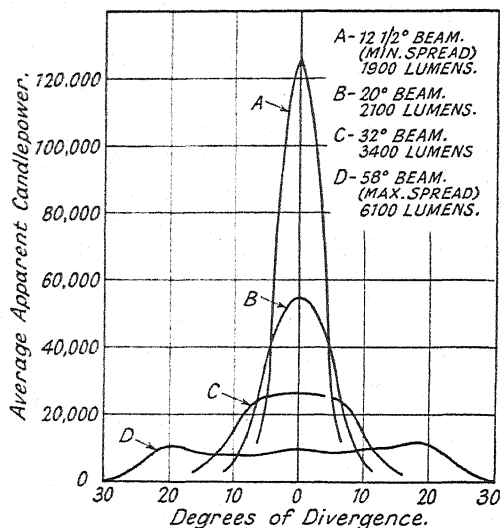


FIG. 39B.—Candlepower distribution from a Mole-Richardson "baby" solar spot, type 406 with a 750-watt, T-24 bulb medium bipost base M.P. type lamp.

lights; or by the kilowatt rating of incandescent units. In some instances the mirror diameter supplies the name. Below are some commonly used terms, the "Lamp Numbers" referring to the preceding sections :

TABLE 8.

<i>Term.</i>	<i>Lamp No.</i>	<i>Term.</i>	<i>Lamp No.</i>
Broad	2-3-11-12	Twenty-four Inky	23-25
Side arc	2-3	5 KW.	23-25
Sixty-five	4	Baby	20-21
Ninety	5	Keg	21
One-seventy	6	Junior	18-19
Twenty-four	7	Senior	16-17
Thirty-six	8	Pan or Skypan	14
Eighty	9	Doubles	11
Rifle	13	10 KW.	24
T-5	25	Strip	15

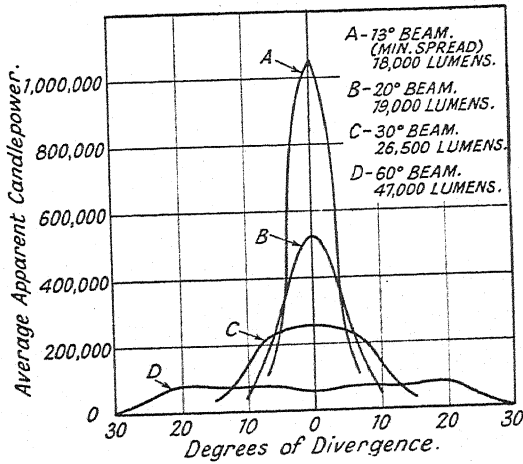


FIG. 39C.—Candlepower distribution from a Mole-Richardson "senior" solar spot type 414, with a 5,000-watt, G-64 bulb mogul bipost base lamp.

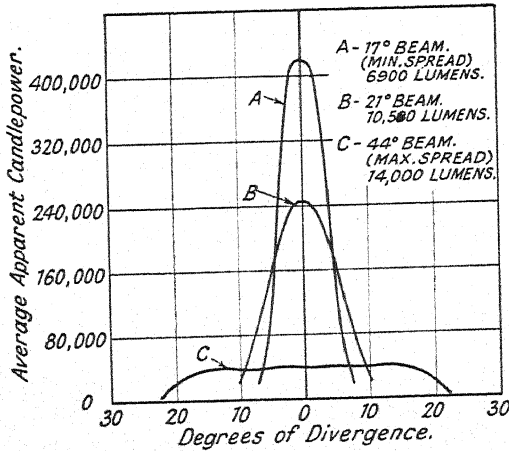


FIG. 39D.—Candlepower distribution from a Mole-Richardson "junior" solar spot type 410 with a 2,000-watt, G-48 mogul bipost base M.P. type lamp.

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The following are a few terms used for material and equipment associated with the use of studio lamps:

Silks.—Frames equipped with china silk diffusers, hung on the fronts of lamps to diffuse the light and reduce the intensity.

Jellies.—Frames equipped with chemically treated gelatine; used for the same purposes as silks.

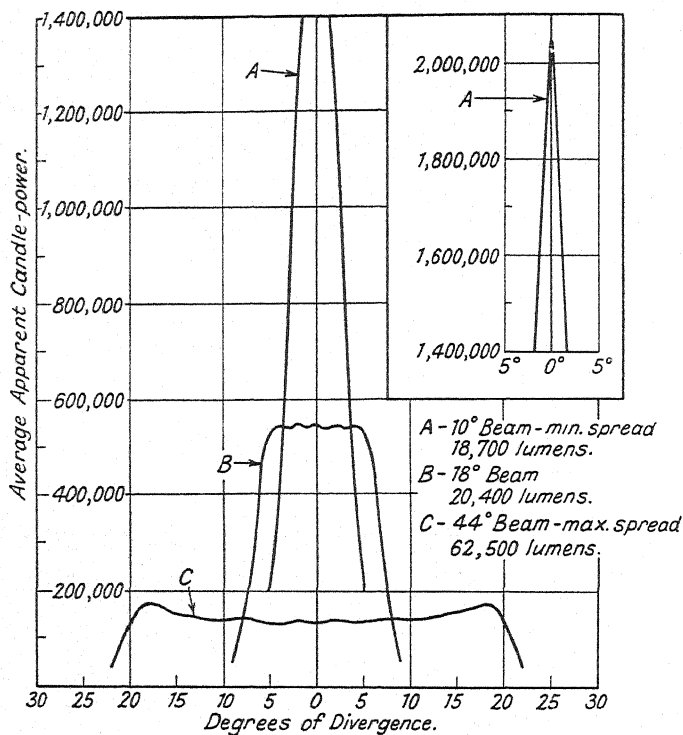


FIG. 39E.

Scrim.—Black gauze; used in various places to reduce intensity and diffuse light.

Diverging Doors.—Strips of cylindrical glass lenses; used on sun arcs for light diffusion.

Snouts.—Various shapes of black sheet-metal hangers; used on the fronts of lamps to block out undesired light.

Spill Rings.—A series of sheet-metal tubes; used in front of incandescent bulbs in mirror-type lamps to block off angular rays emanating from the front surface of the bulb or filament.

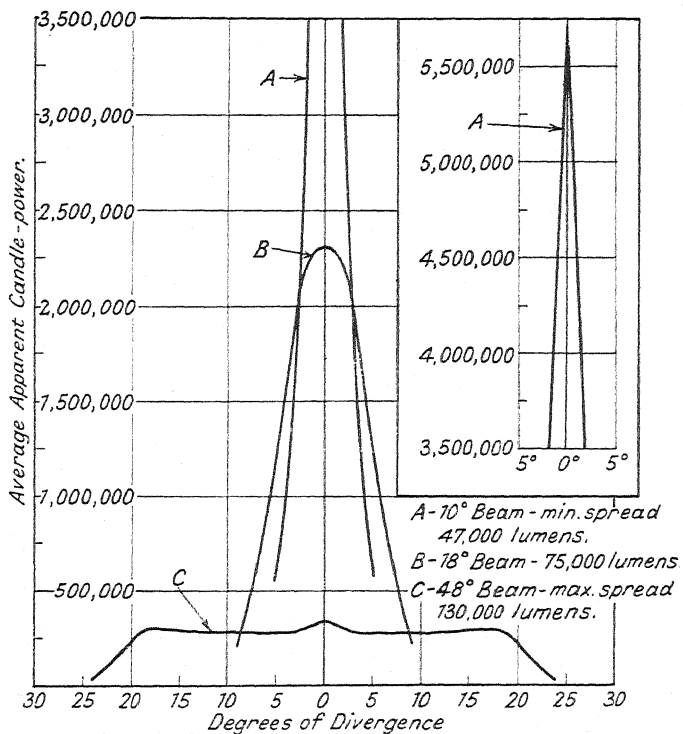


FIG. 39F.—Candlepower distribution from the Mole-Richardson Type 170 Arc Spotlamp.

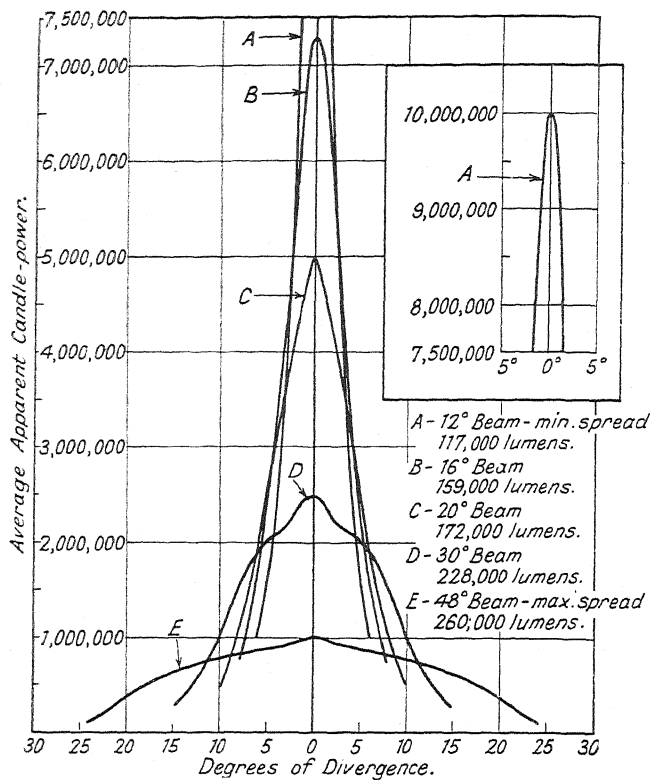


FIG. 39G.—Candlepower distribution from the Mole-Richardson Type 450 Arc Spotlamp.

THE THEORETICAL BASIS

Spot Projector.—A unit equipped with a condenser system that fits on the front of a Type 170 carbon arc lamp in place of the Fresnel-type lens; used to produce a sharply defined round spot of light.

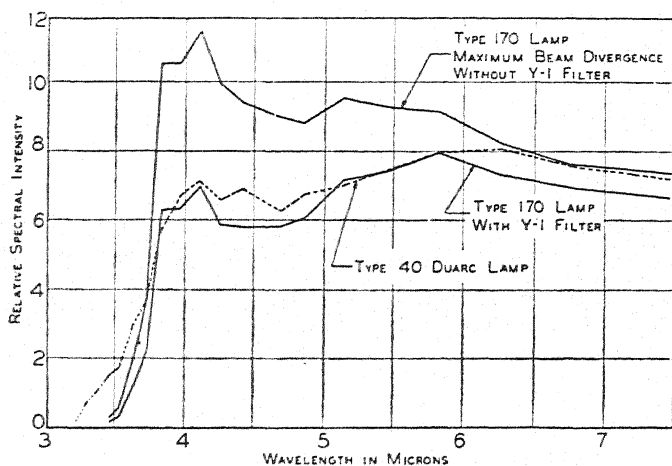


FIG. 40.—Spectral energy distribution of studio light sources. (Bowditch, F. T. Null and Zavesky.) (*Jour. Soc. Mot. Pic. Eng.*, Vol. 46 (March 1942).)

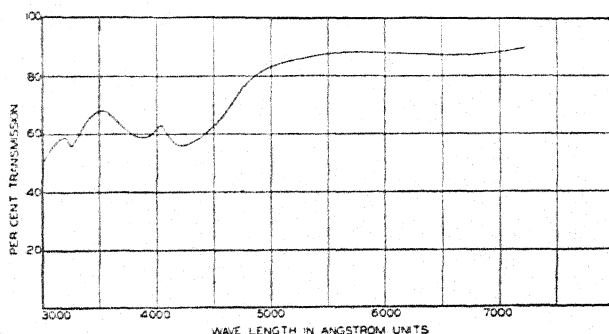


FIG. 41.—Light transmission of gelatine filter No. 53, "Very Light Straw" known as "Y-1" (Brigham Gelatin Co.) (F. T. Bowditch and A. C. Downes, *Jour. Soc. Mot. Pic. Eng.*, 1935.)

Barn Doors, Gobos, Flags, Cheese-cutters, Niggers, etc.—It is often desirable to place opaque screens at various points on a set to keep all or a part of the light from reaching certain areas or objects. These screens are painted dull black and are rectangular, square, or circular, as the occasion may require.

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COLOUR-TEMPERATURE

The system of colorimetric specification, known as the I.C.I.¹ Chromaticity Diagram, which today has been internationally adopted, is based on data representing the mixture of real spectral primaries. Since no three wavelengths can be selected from the spectrum with which all others can be matched without involving negative values, it is necessary, in order to represent all possible mixtures as positive, to hypothesize three primaries which lie outside the spectrum locus and therefore have no real existence. Next it is necessary to assume that the energy of every wavelength represented is exactly equal. Finally that equal proportions of the basic stimuli (theoretical primaries of the system) give a white different to all other whites in that we suppose it to be the one neutral point, all other whites being relatively coloured. It

¹ I.C.I. refers to the International Commission on Illumination, 1931, at which the chromaticity diagram based on the standard observer and coordinate system was adopted. In Britain I.C.I. is known as C.I.E. (Commission Internationale de l'Éclairage).

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must be clear therefore that any change in the relative distribution of energy in the spectrum departing from the condition of equal energy *must result in a colour stimulus*, since *only* an equal energy spectrum can provide a colourless stimulus, by argument. By mathematic computa-

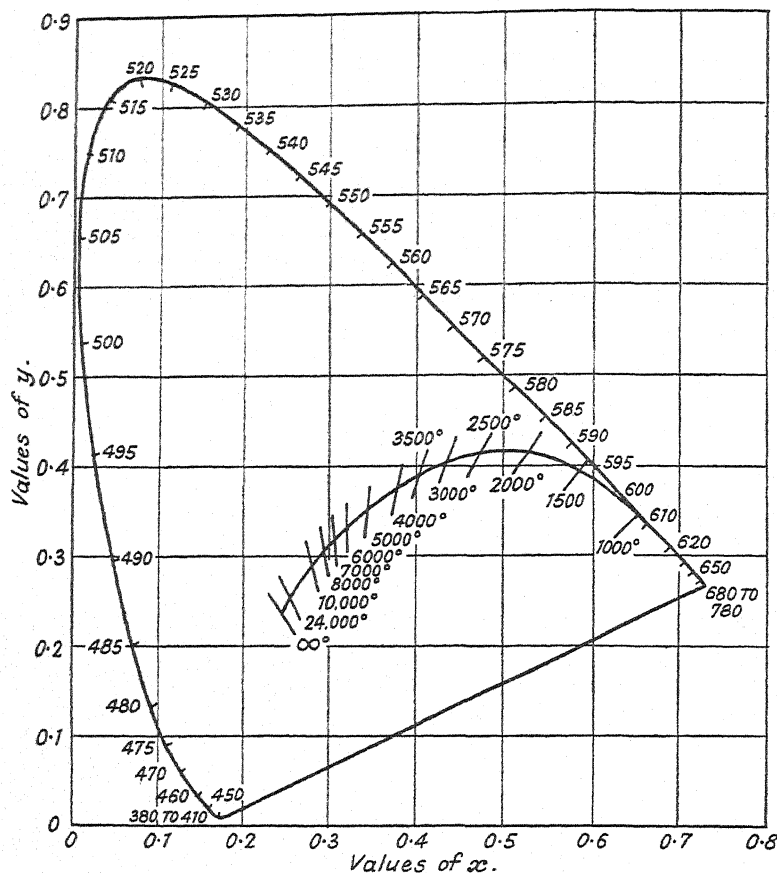


FIG. 42.—Chromaticity diagram showing locus of chromaticities of Planckian radiators and lines of constant correlated colour temperature.

tion we can plot the colour stimulus which must represent every possible distribution of energy.

Colour-temperature has been defined by a Committee of the Colour Group, The Physical Society, London, as “the temperature at which a full radiator would emit radiation of substantially the same spectral distribution in the visible region as the radiation from the light source and which would have the same colours.”

Max Planck, the great German physicist, determined the precise

relation between energy emission and temperature. No emitter of energy can be perfect unless it is an ideal radiator and it can be shown that such a body would be also an ideal absorber, and such a body would be absolutely black. This is the "black body," whose characteristics of radiation provide us with a series of energy curves derived from constants calculated by Planck, and now accepted as fundamental physical data. If the standard tristimulus values are multiplied by the Planckian curves for various temperatures of a black body, we get a curve which can be plotted in the Chromaticity diagram (Fig. 42). It then becomes clear that a perfect radiator would provide a series of colour stimuli varying with its temperature roughly in the order shown in Table 9.

TABLE 9

Deep Red ..	..	..	..	..	800° K.
Orange ..	..	..	..	..	1,200° K.
Whitish Orange ..	..	..	..	..	2,000° K.
Golden White ..	..	..	..	..	2,800° K.
Warm White ..	..	..	..	..	3,500° K.
White ..	..	..	..	..	3,500° K.
Bluish White ..	..	..	..	..	6,500° K.
Whitish Blue ..	..	..	..	..	7,500° K.
Blue ..	..	..	..	..	10,000° K.
Deep Blue ..	..	..	..	..	25,000° K.

But at no point does this curve coincide with the equal energy white, known as E, and to which we referred. Since this curve is a physical standard it has become increasingly the practice to refer the colour of light sources emitting continuous spectra, and therefore roughly corresponding to "black bodies," to the nearest point they would match in the black body temperature scale. Although fluorescent lamps and discharge lamps generally provide "whites" of different hue we cannot truly assign such whites to a position in the colour-temperature range, nevertheless they can be given an equivalent position (Fig. 43).

Three important points in the scale have been adopted as standard illuminants: Illuminants A, B and C, representing respectively, 2848° K., 4800° K., and 6500° K.

The measurement of colour-temperature may be effected by comparison with a tungsten lamp running at exactly determined voltages, but direct use of this method is limited to colours produced by temperatures below the melting point of tungsten.

The second method requires a spectrophotometric measure of the relative energy at each wavelength in the spectrum of the source being measured—followed by computation enabling its chromaticity point (hence its colour) to be plotted.

Thus we find that the domestic 100-W. incandescent tungsten lamp has a colour temperature of 2,865° K., while a 1,000-W. projection lamp has a colour temperature of approximately 3,250° K. The low-intensity

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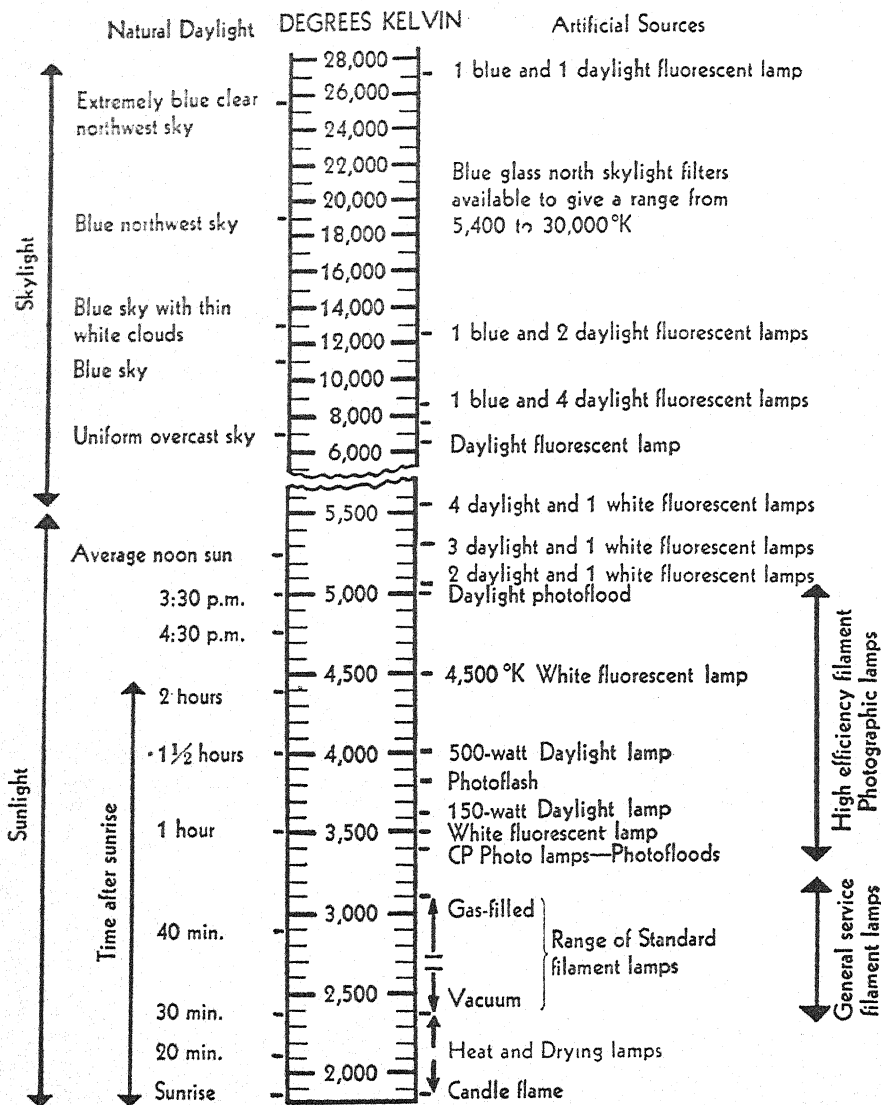


FIG. 43.—Colour temperature chart.
(By courtesy of the General Electric Company, U.S.A.)

arc is higher at 3,550° K., and finally the high-intensity arc at 5,000-6,500° K. is close to sunlight. Light sources above this temperature are even more blue.

Fig. 44 shows the relative sensitivity of panchromatic film to radiation

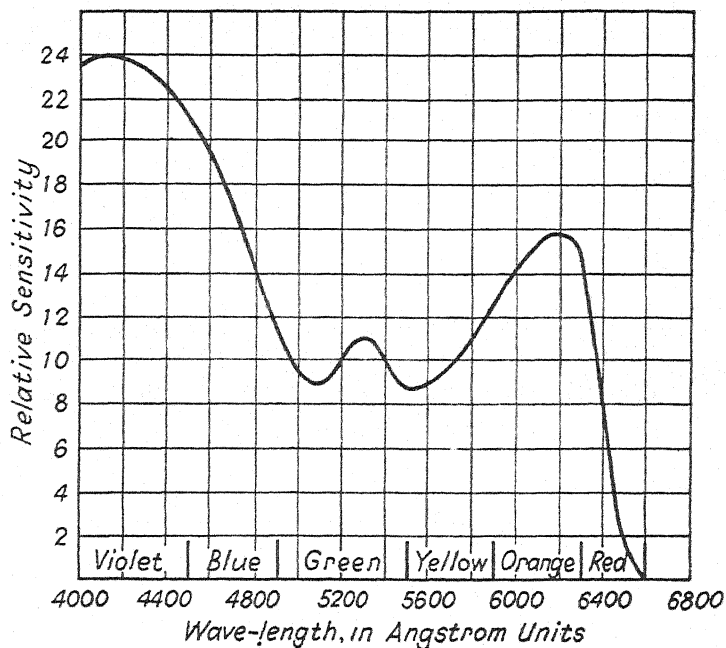


FIG. 44.—Relative sensitivity of photographic film vs. wavelength of radiation. (Linderman, Handley and Rodgers.)

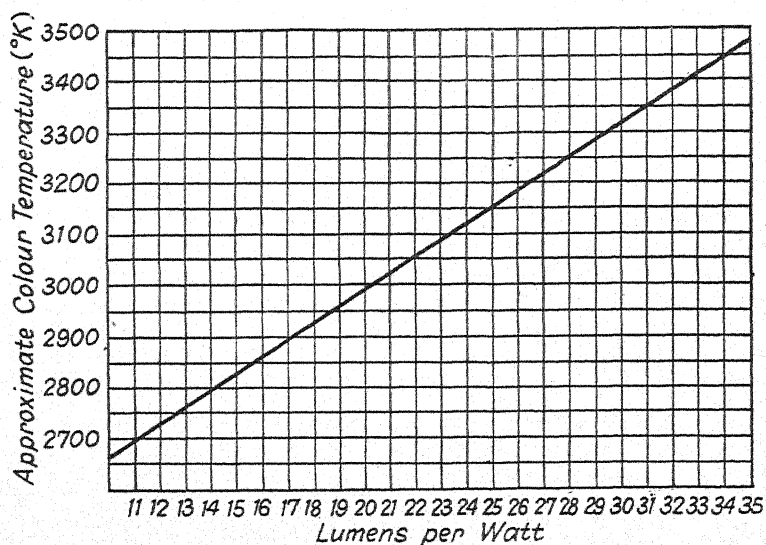


FIG. 44A.—Colour-temperature vs. efficiency of Mazda C lamps. (Linderman, Handley and Rodgers.)

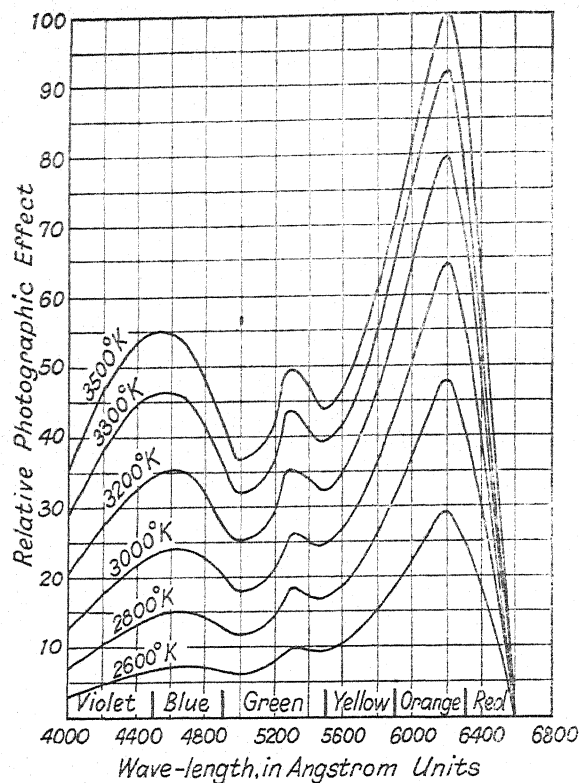


FIG. 45.—Relative photographic effectiveness of light-sources of equal wattage and various colour-temperatures. (Linderman, Handley and Rodgers.)

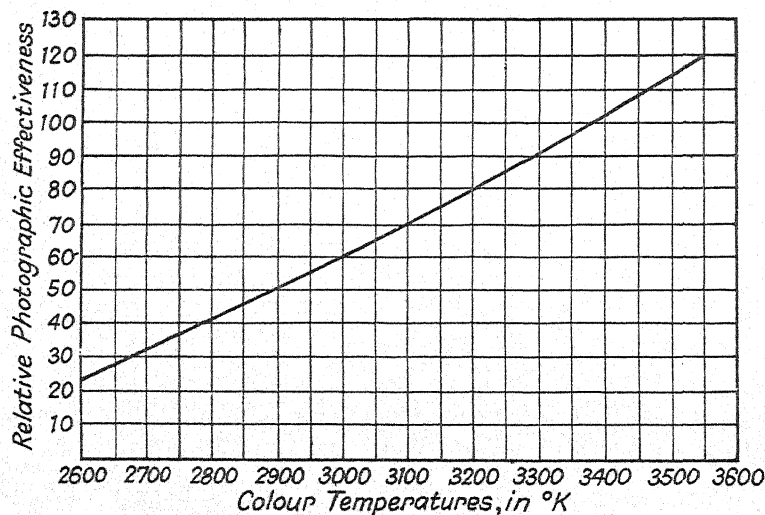


FIG. 46.—Relative photographic effectiveness vs. colour-temperature. (Linderman, Handley and Rodgers.)

in the visible region. Fig. 45 illustrates the shift in relative photographic effectiveness with change of colour-temperature, the light source being of constant wattage. Fig. 46 sets forth the relative photographic effectiveness at different colour-temperatures.

A Colour-Temperature Meter

Small differences of colour-temperature are sufficient to shift the balance of exposure in all systems of three-colour photography. Integral layer materials such as Kodachrome or Ansco Color film are indicated by the manufacturer as balanced for exposure by light of a stipulated colour-temperature. The user can check the colour-temperature of a given source of light by using a simple instrument such as the Eastman colour-temperature meter. This apparatus functions in the following manner:¹

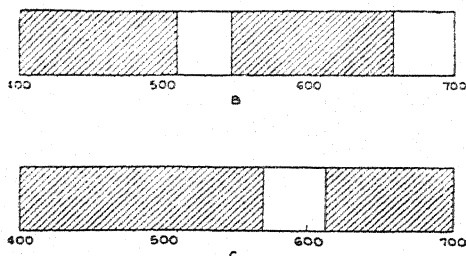


FIG. 47.—Diagram showing spectral regions used in the colour-temperature meter.

Suppose that in some way we block out or absorb certain components of the light from an incandescent source as represented by the shaded areas in Fig. 47. We have left narrow bands in the green and red which if combined will produce a visual impression of yellow or orange. This orange will appear to the eye as though the shaded areas in Fig. 47 had been removed and only a single narrow strip allowed to pass. In other words, a mixture of a properly selected narrow band of wavelengths from the green region with another from the red will produce the same visual impression as that of a single small group in the yellow-orange portion of the continuous spectrum.

In the Eastman colour-temperature meter the selection of the proper portions of the spectrum is accomplished by means of carefully constructed light filters. One of these filters is so made up that it possesses two transmission bands with maximum transmittance at about $520M\mu$ and $680M\mu$ respectively. The second filter is so composed that the wavelength of its maximum transmittance is at approximately $580M\mu$. The relative transmittances of the bands in the two-band or dichroic

¹ Description extracted from Communication No. 698, Kodak Research Laboratories, "A Color-Temperature Meter," by E. M. Lowry and E. S. Weaver.

filter are so adjusted that, when examined by light—for example, that from a tungsten lamp operating at a colour-temperature of $2,100^{\circ}\text{K}$.—its colour will be the same as that of the filter with its maximum transmittance at $580\text{M}\mu$. For colour-temperatures higher than $2,100^{\circ}\text{K}$. the dichroic filter will appear more green than the monochromatic one, while for temperatures lower than $2,100^{\circ}\text{K}$. it will appear more red. This property of dichroic materials was shown by Pflüger in his work on anomalous dispersion, and was discussed by Wood in his *Physical Optics*.

The reason for this behaviour may be explained by reference to Fig. 48. Curve A represents the spectrophotometric transmission

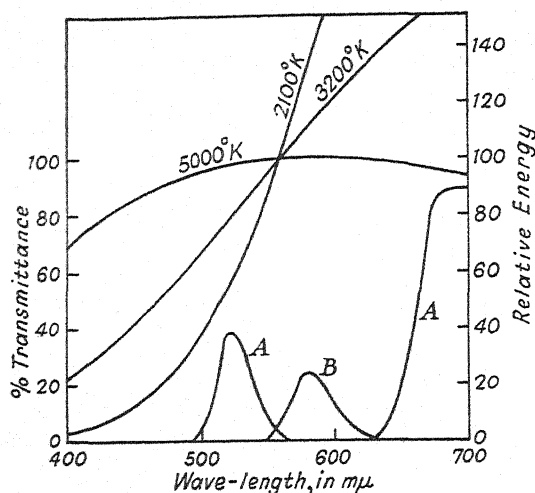


FIG. 48.—Spectrophotometric transmission curves of field filters used in colour-temperature meter and relative energy distribution for colour-temperatures of $2,100^{\circ}\text{K}$, $3,200^{\circ}\text{K}$, and $5,000^{\circ}\text{K}$.

curve of the two-band filter, which has two maxima, at $520\text{M}\mu$ and at $680\text{M}\mu$ respectively. Curve B is that of the monochromatic filter, which possesses a transmittance maximum at $580\text{M}\mu$. As stated above, the relative transmittances of the two bands for filter A have been so adjusted that, when examined by light from a source operating at $2,100^{\circ}\text{K}$., this filter will appear to be the same colour as filter B. The curve labelled $2,100^{\circ}\text{K}$. represents the relative energy emitted at the various wavelengths of the visible spectrum by the source operating at $2,100^{\circ}\text{K}$., which is the temperature at which the filters will be colour-matched. A source working at a colour-temperature of $3,200^{\circ}\text{K}$. will emit energy of somewhat different distribution at the various wavelengths. Examination of the two distribution curves

shows that the energy emitted is relatively higher at $520\text{M}\mu$ and relatively less at $680\text{M}\mu$ for $3,200^\circ\text{K.}$ than for the $2,100^\circ\text{K.}$ source. This will result in more light passing through the $520\text{M}\mu$ band in A and less at $680\text{M}\mu$, and there will be a change in the colour of the filter such that it will appear more green than when examined with the $2,100^\circ\text{K.}$ source. In the case of filter B, however, there will be relatively little change in hue and it will still be yellow. If the colour-temperature of the source is reduced below $2,100^\circ\text{K.}$ —for example, to $2,000^\circ\text{K.}$ —the filter A will appear more red than B because the ratio of energies in the regions of the spectrum at the positions of maximum transmittance of the filters has changed so that there is relatively more energy in the red portion than at the original match-point—namely, at $2,100^\circ\text{K.}$

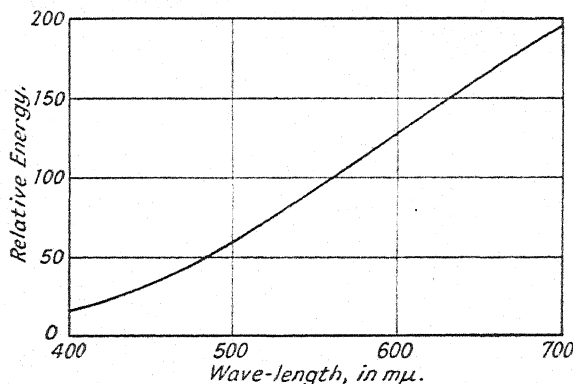


FIG. 49.—Graph showing relative spectral distribution of energy for a 100-watt tungsten lamp.

In order that the two filters shall remain colour-matched when the colour-temperature of the source is other than $2,100^\circ\text{K.}$ it is necessary to modify the energy distribution of the source in some way. This modification may be accomplished by changing the voltage applied to the lamp until its colour-temperature is once more that of the original. The necessary change in voltage may be used as a measure of the difference from $2,100^\circ\text{K.}$ Another method of accomplishing the desired result is to absorb a portion of the radiant energy selectively with respect to wavelength in such a way that the remainder matches that at the initial temperature. Filters of this type, such as the so-called daylight glasses or the Wratten Photometric Series of filters, are well known. In the present instance we are interested in reducing the colour-temperature, since the match-point for the filters is lower than that of most practical light-sources, and we require an amber-coloured filter. This amber filter is made up in the form of a wedge, and the amount of

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selective absorption is dependent upon the thickness of the wedge at any point. The greater the thickness of the portion of the wedge used, the greater is the reduction in colour-temperature of the light transmitted.

In the colour-temperature meter the principles just described have been applied as illustrated in Fig. 50A. A circular photometric field P, with a fine dividing line across the centre, is formed by the narrow band-filters whose absorption characteristics are illustrated in Fig. 48.

The left half of the field, which is shown in detail at B, is formed by the dichroic filter, and the right half is formed by the monochromatic one. Between the eyepiece lens E and the test field is an amber wedge W for the purpose of modifying the energy distribution of the light

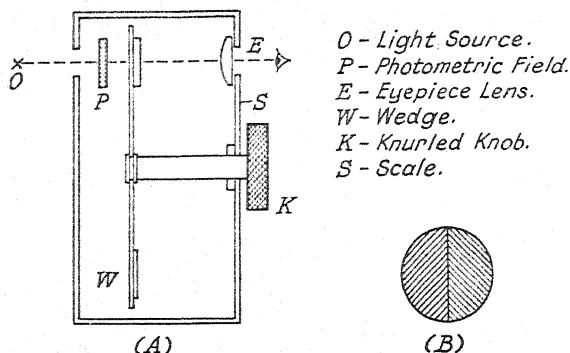


FIG. 50A.—Illustrative diagram of colour-temperature meter.

from the source being examined. This wedge is circular and the portion of the wedge to be used is selected by means of a small knurled knob K. The scale of the instrument S is so calibrated that it reads directly the colour-temperature of the source investigated.

Fig. 50 is a photograph of the instrument depicting both front and side views. Comparison of the reproduction of the meter with the 6-in. rule at the bottom of the picture illustrates the compactness and convenient size of the design.

Actual operation of the meter is accomplished by the observer directing the visual axis of the instrument (dotted line in Fig. 50A) towards the source in question. He then observes whether the two halves of the field of view are colour-matched and, if they are not, adjusts the position of the wedge until such a colour-match is obtained. A clockwise motion of the wedge increases the amount of absorption, while a counterclockwise motion decreases it. The farther the wedge must be inserted, the higher is the corresponding colour-temperature as read from the scale.

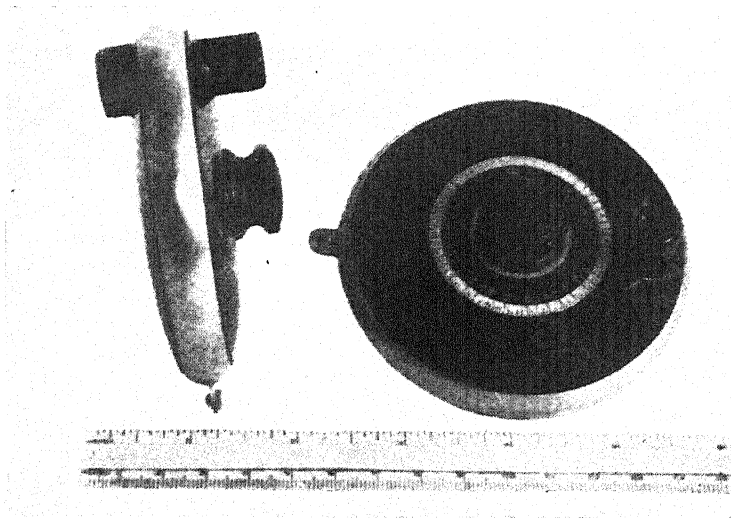


FIG. 50.—Eastman colour-temperature meter.

Because of the fact that there are certain slight differences between the eyes of different individuals, the dichroic and monochromatic filters are not always colour-matched at the same colour-temperature. For this reason some means of compensation must be provided if determinations made with the instrument are to be in satisfactory agreement for two or more observers. To overcome this difficulty an accommodation scale has been provided which enables each individual to select the initial setting of the amber wedge which suits his particular eye. Before making any measurements, each observer must set the scale of the instrument at the value corresponding to a source of known colour-temperature. A tungsten lamp which has been calibrated properly would serve admirably for this purpose, but, since such a lamp must be operated at constant voltage, auxiliary equipment is required which is not always available. Beeswax candles, such as, for example, the XXX Superior Candles made by the Socony-Vacuum Oil Company, are easily obtained and, since they possess fairly uniform temperature characteristics ($1,935^{\circ} \text{ K.} \pm 10^{\circ}$), they are quite suitable for the purpose of adjusting the accommodation scale when used with the auxiliary blue filter. This filter, which raises the colour-temperature of the candle flame to a point above $2,100^{\circ} \text{ K.}$, is supplied on an easily attached mount.

To make the initial adjustment the operator first sets the point in the scale marked C opposite the index. Then, while applying pressure to the scale with the thumb of one hand to prevent any displacement of the scale relative to the index, he rotates the knob with the other hand until a colour-match is obtained in the field of view. During this operation the candle flame is the illuminant. After the preliminary adjustment the meter is in condition for reading the colour-temperature of some unknown source.

The precision of the measurements made with the colour-temperature meter depends upon certain fundamental requirements. In the first place the operation of the instrument is based upon the ability of an observer to do colour-matching, and therefore assumes his colour vision to be normal—that is, he must not be colour-blind or have any noticeable deficiencies in colour vision. In the use of the meter, as in all operations requiring the application of optical instruments, the precision of setting is considerably improved by practice. The first few attempts to balance the field by an individual unskilled in this type of measurement are likely to show very erratic results, but as he becomes accustomed to the manipulations necessary his repeatability will improve and his results will be quite satisfactory.

In Table 10 are shown the average deviations from the mean of ten settings made by each of three observers at the colour-temperature indicated.

We must not overlook the fact that colour-temperature is a visual

TABLE 10.—SHOWING PRECISION OF MEASUREMENTS WITH THE COLOUR-TEMPERATURE METER (EASTMAN KODAK)

<i>Observer.</i>	<i>Temperature, °K.</i>	<i>Average Departure from Mean of Ten Settings.</i>
EML	2,360	14
AS	2,360	24
KSW	2,360	15
EML	2,660	15
AS	2,660	30
KSW	2,660	22
EML	2,850	22
AS	2,850	26
KSW	2,850	28
EML	3,200	21
AS	3,200	35
KSW	3,200	34

measurement only, a given position on the chromaticity chart not being a definition of energy distribution, since a practically infinite number of possible distributions of energy can evoke the same sensation. We must remember that in colour photography we are supremely concerned with distribution of energy in the light-source on the one hand and the sensitivity in the region of the visible spectrum of the photographic material we are employing on the other. The measurement of colour-temperature will therefore be understood to be only a rough guide as to the suitability of a given source of light. On the other hand, any local change in a very restricted part of the spectrum would be likely to give rise to a change of colour-temperature which would be perceived with an instrument such as the Eastman meter—that is, under practical conditions. It would not be difficult to imagine instances, however, which would lead to incorrect assumptions being made as a result of the measurement of colour-temperature alone.

Other colour-temperature meters have been recently made available, such as the Norwood colour-temperature meter, designed by Capt. Don Norwood, of Los Angeles, the "Spectra," made by the Photo Research Corporation, of Hollywood, and the "Helios," made by Helios, of London.

GENERAL ILLUMINATION DATA

TABLE 11 (BOWDITCH AND DOWNES).—COLOUR-TEMPERATURE OF CARBON ARCS WITH DOMINANT WAVELENGTH AND PER CENT. PURITY REFERRED TO AVERAGE DAYLIGHT

<i>Light-Source.</i>	<i>Current.</i>	<i>Voltage.</i>	<i>Colour-Tem- perature, °K.</i>	<i>Dominant Wave- length, Angstrom Units.</i>	<i>Per Cent. Purity.</i>
<i>Average Daylight:</i>					
11-mm. H.I. Carbons	90	56.5	6,500		
8-mm. Suprex Carbons	65	38	6,400	5,640	4
8-mm. Suprex Carbons	56	43	6,250	5,650	5
16-mm. H.I. Carbons	150	81	6,000	5,700	5
7-mm. Suprex Carbons	50	36	5,950	5,740	7
1/2 x 12 Rotary Spot Carbons ..	80	53	5,600	5,710	9
6-mm. Suprex Carbons	40	32	5,850	5,900	9
9-mm. H.I. Carbons	70	49	5,800	5,750	9
7-mm. Suprex Carbons	42	33	5,800	5,760	9
13-6-mm. Super H.I. Carbons ..	185	75	5,480	5,740	10
13-6-mm. H.I. Carbons	125	63	5,650	5,730	12
6-mm. Suprex Carbons	30	28	5,250	5,770	16
8-mm. Nat. M.P. Studio Carbons	40	37.5	4,650	5,780	25
12-mm. L.I. Carbons	30	55	3,550	5,830	40

TABLE 12 (BOWDITCH AND DOWNES).—COLOUR-TEMPERATURE OF CARBON ARCS WITH DOMINANT WAVELENGTH AND PER CENT. PURITY REFERRED TO NOON JUNE SUNLIGHT AT SPRINGFIELD LAKE, OHIO

<i>Light-Source.</i>	<i>Current.</i>	<i>Voltage.</i>	<i>Colour-Tem- perature, °K.</i>	<i>Dominant Wave- length, Angstrom Units.</i>	<i>Per Cent. Purity.</i>
<i>Noon June Sunlight:</i>					
8-mm. Nat. M.P. Studio Carbons	40	37.5	4,200		
12-mm. L.I. Carbons	30	55	4,650	4,750	6
6-mm. Suprex Carbons	30	28	3,550	6,050	9
13-6-mm. Super H.I. Carbons ..	185	75	5,250	4,780	13
13-6-mm. H.I. Carbons	125	63	5,480	4,800	14
9-mm. H.I. Carbons	70	49	5,650	4,800	16
7-mm. Suprex Carbons	42	33	5,800	4,780	17
1/2 x 12 Rotary Spot Carbons ..	80	53	5,800	4,790	17
6-mm. Suprex Carbons	40	32	5,600	4,750	17
16-mm. H.I. Carbons	150	81	5,850	4,790	18
7-mm. Suprex Carbons	50	36	6,000	4,780	18
8-mm. Suprex Carbons	56	43	5,950	4,800	19
8-mm. Suprex Carbons	65	38	6,250	4,790	20
11-mm. H.I. Carbons	90	56.5	6,400	4,800	21
			6,400	4,800	22

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TABLE 13.—THE CHROMATICITY COORDINATES OF IMPORTANT ILLUMINANTS (A. C. HARDY)

Source. Black Body at:	x.	y.
1,000° K.	0.6524	0.3448
1,500° K.	0.5852	0.3934
1,900° K.	0.5372	0.4114
2,360° K.	0.4893	0.4150
2,848° K.	0.4476	0.4075
3,500° K.	0.4049	0.3906
4,800° K.	0.3506	0.3560
6,500° K.	0.3133	0.3225
10,000° K.	0.2806	0.2883
24,000° K.	0.2532	0.2532
I.C.I. Illuminant A	0.4476	0.4075
I.C.I. Illuminant B	0.3485	0.3518
I.C.I. Illuminant C	0.3101	0.3163
Mean Noon Sunlight	0.3442	0.3534
Sun Outside Atmosphere	0.3204	0.3301

TABLE 14.—RANGE OF ELECTROMAGNETIC RADIATIONS

Radiation.	Lower Range of Wavelength.	
	Angström Units.	Corresponding Electron Volts.
Gamma Rays	0.1	123,360
X-rays	1.0	12,336
Far Ultra-violet	1,000	12.34
Near Ultra-violet	3,000	4.11
Visible	4,100	3.01
Infra-red	7,200	1.71
Shortest Hertzian Waves	$10^7=0.1$ cm.	10^{-8}
Radio Waves	1 metre	10^{-6}
	1 kilometre	10^{-9}

1 Angström Unit= 10^{-8} cm.

The third column (Table 14) gives the voltage through which an electron would have to be accelerated to cause the emission of the given wavelength.

There is a definite relation between the two magnitudes which is expressed by the relation

$$\lambda = \frac{V}{12,336}$$

where λ is the wavelength in Angstrom units and V is measured in volts.

THE THEORETICAL BASIS

Based upon the data of the distribution of energy in the spectrum of any light-source and the relative spectral luminance curve (see page 224), the theoretical optimum efficiency can be calculated. Call this L_o . Table 15 gives values of L_o for different sources compared with efficiency values L_s obtained on actual lamps. The third column gives the percentage 100η of the total energy emitted by the source that is in the visible range. This is deduced by means of the relation

$$\eta = L_s / L_o$$

The last column gives the energy utilization ratio ϵ —that is, the ratio between the total watts input and the watts emitted as visible light (which is measured in terms of lumens).

TABLE 15.—LUMINOUS EFFICIENCIES OF VARIOUS SOURCES OF LIGHT (LUMENS PER WATT) (S. DUSHMAN, G.E.C., U.S.A.)

Source.	L_o .	L_s .	100η .	100ϵ .
Black Body at T=6,500	218	86.3	39.5	13.9
Sun	250	100	40	16.1
Tungsten (Gas-filled)	143	15-30	10-20	2.5- 5.0
Flaming Arc	220	45-75	20-34	7.2-12.1
Sodium Vapour	475	50-75	10-15	8 -12
Mercury Vapour (Low Pressure)	248	15-20	6- 8	2.5- 3.2
1 Atm. (Type H)	298	30-35	10-12	4.8- 5.6
Higher Pressures	298	40-50	13-17	6.4- 8.0
Neon	198	15-40	7.5-20	2.5- 6.4
Helium	—	4-10	—	—
Carbon Dioxide	—	2- 4	—	—
Cadmium	—	0.5-1	—	—
Green Fluorescent (L.P. Mercury)	475	60-80	12.6-16.9	9.6-12.9

TABLE 16.—TEMPERATURES OF LIGHT-SOURCES¹

Tungsten Incandescent Gas-filled Bulb, 1,000 watts (20.5 l./w.)	3,010° K.
Photoflood Lamp. Tungsten Lamp at overvoltage	3,500° K.
Artificial Daylight Lamp. Relative temperature	3,570°-4,100° K.
Neutral Cored Carbon Arc	4,000° K.
High-Intensity Arc	4,800°-5,000° K.
Direct Sunlight	5,100° K.
Noon Sunlight in latitude of Washington	5,400° K.
Total Daylight	5,640° K.

¹ Colour-temperatures are expressed on the absolute scale in which temperatures are measured from a zero approximately 273° below the freezing-point of water. The absolute scale is also known as the Kelvin scale.

TABLE 17.—COLOUR-TEMPERATURE AND WAVELENGTH OF MAXIMUM ENERGY

Colour-Temperature $C_2=14384.8$.	Wavelength of Maximum Energy ($M\mu$).	Chromaticity Co-ordinates.	
		x.	y.
1,000° K.	2,880	0.6524	0.3448
2,000° K.	1,440	0.5266	0.4133
2,500° K.	1,152	0.4769	0.4136
3,000° K.	960	0.4368	0.4040
3,500° K.	823	0.4052	0.3907
4,000° K.	720	0.3804	0.3767
6,000° K.	480	0.3220	0.3317
8,000° K.	360	0.2951	0.3048
10,000° K.	288	0.2806	0.2883

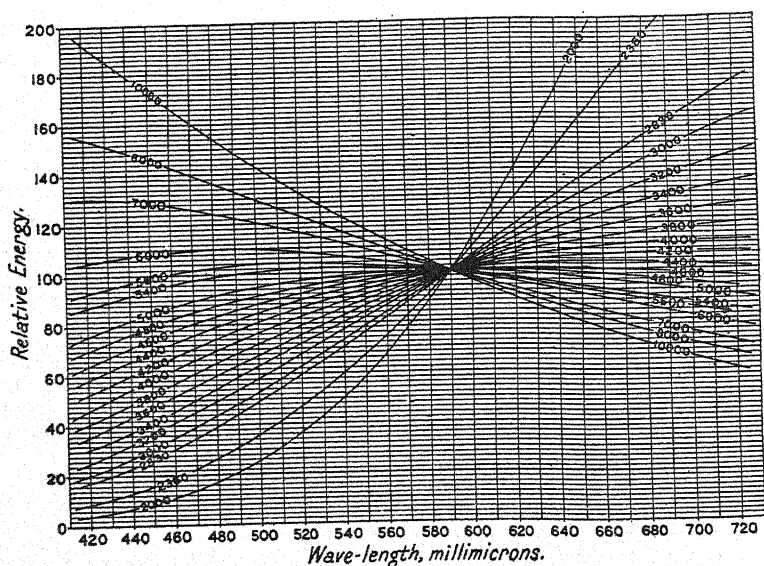


FIG. 51.—Planckian distributions of energy at various temperatures. Planck's constant, $c_2=14384.8$ micron-degrees. Numbers attached to the curves indicate temperatures in °K. (absolute temperature). Ordinates of the different curves are arbitrarily made equal at wavelength 590.

TABLE 18.—INTRINSIC LUMINANCE OF LIGHT-SOURCES

<i>Light-Source.</i>	<i>Candle Power per Sq. Mm.</i>
High-Intensity White-Flame Carbon Arc (Forced)	1,200
Pure Carbon Arc at 22 atmospheres	1,000
Sun at Zenith	920
High-Intensity White-Flame Carbon Arc as usually operated	690
Positive Crater of Tantalum Arc (about)	500
" " " Solid Carbon Arc on D.C.	180
" " " Cored Carbon Arc on D.C.	130
Yellow Arc Stream	8.0
Magnetic Arc Stream	6.2
Mercury Vapour Tube	0.023
Moore Carbon Dioxide Tube	0.009

TABLE 19.—CHROMATICITY CO-ORDINATES OF VARIOUS ILLUMINANTS

<i>Light-Source.</i>	<i>Correlated Colour- Temperature.</i>	<i>Chromaticity Co-ordinates.</i>	
		<i>x.</i>	<i>y.</i>
I.C.I. Illuminant A	2,850° K.	0.4476	0.4075
I.C.I. Illuminant B	4,880° K.	0.3485	0.3518
I.C.I. Illuminant C	6,740° K.	0.3101	0.3163
Mean Noon Sunlight	5,035° K.	0.3442	0.3534
Direct Sunlight at Sea Levels	5,080° K.	0.3431	0.3567
Direct Sunlight	5,335° K.	0.3362	0.3502
Sun plus Sky	6,000° K.	0.3213	0.3348
Overcast Sky	6,500° K.	0.3134	0.3275
North Sky on 45° Plane	10,000° K.	0.2773	0.2934
Equal Energy Spectrum	5,500° K.	0.3333	0.3333
Carbon Arc	6,400° K.	0.3152	0.3325

NOTES ON PHOTOMETRIC TERMS

The unit of solid angle is known as a *Steradian*.

- 1 *Steradian*=solid angle subtended at the centre of a sphere by an area on the spherical surface equal to the square of the radius.
(Area of a sphere= $4\pi r^2$. Thus total solid angle at a point= 4π steradians.)

Units of Flux

The unit of luminous flux is known as the *Lumen*.

- 1 *Lumen*=the flux emitted in a steradian by a uniform point source of 1 candle.

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Mean Spherical Intensity or Candle-Power $4\pi \times \text{M.S.I.} = \text{total flux in lumens.}$

Illumination at a point of a surface is the density of the luminous flux at that point, or the quotient of the flux by the area of the surface.

1 *Lux* = 1 *Lumen* per sq. m.

1 *Foot-candle* = 1 *Lumen* per sq. ft.

Units of Luminance

The luminance in a given direction of a surface emitting light is the quotient of the luminous intensity measured in that direction by the area of this surface projected on a plane perpendicular to the direction considered.

The unit of luminance is 1 *candle* per unit area of surface.

Illumination in foot-candles \times incident reflection factor of surface = luminance in *Foot-lamberts*.

1 *Lambert* = a perfect diffuser emitting 1 lumen per sq. cm.

1 *Millilambert* = $\frac{\text{Lambert}}{1,000}$.

1 *Foot-lambert* = a surface emitting 1 lumen per sq. ft.

A perfectly reflecting and diffusing surface illuminated with an intensity of 1 foot-candle would possess a surface luminance of 1.076 millilamberts.

Unit of Retinal Illumination

1 *Photon* = 1 candle per sq. m. received through pupil area of 1 sq. mm.

Least energy perceptible to the eye = 42×10^{-11} erg. per sec.—viz., 0.00156 lumens per watt for wavelength 5,560 Å. Or, 1 watt should yield 641 lumens. Energy value at the absolute threshold is 4.2×10^{-11} watt; therefore value in lumens is $2.7 \times 10^{-13} = 7.3 \times 10^{-9}$ candle 1 m. from the eye.

Under dark adaptation a square whose sides subtend an angle of 2° at the eye must have a luminance of two-millionths of a foot-lambert if it is to be detected.

2. THE SECONDARY LIGHT-SOURCE

The colour of a surface of matter varies owing to its power to absorb, reflect, or transmit light. These effects may be selective, and, indeed, generally are so. We know that our sensation of hue is caused by light lacking in some component which if added would give the sensation white; in this way, by the subtraction of some of the elements of

TABLE 20.—CONVERSION FACTORS FOR ILLUMINATION UNITS

	<i>Lux.</i>	<i>Millilphots.</i>	<i>Foot-Candles</i> (1 Lumen per Sq. Ft.).
<i>Lux</i> ..	1	0.1	0.092903
<i>Millilphots</i> ..	10	1	0.92903
<i>Foot-candles</i> ..	10.764	1.0764	1

TABLE 20A.—CONVERSION FACTORS FOR LUMINANCE UNITS

	<i>Candles per Sq. Cm.</i>	<i>Candles per Sq. M.</i>	<i>Candles per Sq. In.</i>	<i>Candles per Sq. Ft.</i>	<i>Lamberts.</i>	<i>Milli-lamberts.</i>	<i>Foot-Lamberts</i> (Lumens per Sq. Ft.).
<i>Candles per sq. cm.</i> ..	1	10,000	6.452	929.0	3.1416	3141.6	2,919
" " m. ..	0.0001	1	0.0006452	0.9290	0.00031416	0.31416	0.2919
" " in. ..	0.1550	1,550	1	144	0.4869	486.9	452.4
" " ft. ..	0.0010764	10.764	0.006944	1	0.003382	3.382	3.1416
<i>Lamberts</i> (apparent lumens per sq. cm.) ..	0.3183	3,183	2.054	295.7	1	1,000	929.0
<i>Millilamberts</i> ..	0.0003183	3.183	0.002054	0.2957	0.001	1	0.9290
<i>Foot-lamberts</i> (equivalent foot-candles, apparent lumens per sq. ft.) ..	0.0003426	3.426 ($\frac{1}{\pi} \times 10.764$)	0.00214	0.3183 ($\frac{1}{\pi}$)	0.0010764	1.0764	1

1 equivalent foot-candle is the luminance of a perfect diffusing surface of 100 per cent. reflection factor receiving an illumination of 1 foot-candle.

$$1 \text{ e.f.c.} = \frac{1}{\pi} \text{ candles/sq. ft.}$$

The unit of luminance of a perfect diffuser is the emission of 1 lumen (1 candle-power = 4π lumens) per unit area. A lambert is 1 lumen per sq. cm., while a foot-lambert is 1 lumen per sq. ft. Therefore 1 millilambert = 0.93 foot-lamberts, since 1 sq. ft. = 929 sq. cm.

white light, the colours of material objects originate. If the surface of the material is polished and regular the reflection therefrom will be of that type known as *direct*. In this case, regardless of the light-absorbing property of the material, within a certain angle nearly all the incident light will be reflected. The surface of a piece of red glass, for example, can reflect light just like a mirror within a certain angle, whereas at another angle it will appear a saturated red. Sometimes selective absorption occurs in the outer layers of a polished object. At the angle at which direct reflection is avoided such an object will be more saturated in colour than a non-polished, diffusely reflecting surface. This effect is familiar in the increased "richness" in the appearance of a surface after polishing or varnishing.

The characteristic absorption of the principal pigments and dyes should be studied by those engaged in the art direction of colour films, because it is important to be able to predict the reproduction with some approximation to accuracy. The usual method of presenting the absorption, or reflection, factors of a pigment, or a dye, is in the form of a curve representing the reflection, or transmission, factors of the colouring medium for radiant energy of all wavelengths in the visible spectrum. When these are plotted we have the curves representing the spectral reflection or transmission factors for the visible spectrum. Typical spectrophotometric data are plotted in the curves in Figs. 52 and 53, from *Color and its Applications*, by M. Luckiesh. These curves are the spectral reflection factors of a number of familiar pigments. Table 21 gives the data from which the curves were plotted. The method generally adopted is to compare the intensity of the light reflected from the pigment with that reflected from the surface of some standard white such as magnesium carbonate.

The eye is not an analytical instrument. We cannot detect, for example, the presence of the band of rays in the extreme red end of the spectrum in nearly all the basic dyes and many pigments. This band of red is of considerable importance in colour photography, and is one of the reasons why certain greens, blue-greens, and blues, commonly met with in dress fabrics, are so difficult to reproduce; for if there is light recorded through the red filter we shall obtain density on the negative and therefore proportionately less cyan printed on the positive.

Dye lakes known as "poster colours" are generally used for the painting of cartoons in colour. Such poster colours are nearly always made from basic lakes, and care must be exercised in the use of greens, blue-greens and blues.¹

¹ The new pigment "Monastral Fast Blue BS," manufactured by Imperial Chemical Industries Limited, has none of the defects of previous blue pigments. It is the ideal blue for purposes of colour photography, since it reflects very little red light. It will supplant ultramarine and cobalt blue, and it is far superior to Prussian blue, known as "Winsor Blue" in the Winsor and Newton range.

TABLE 21.—SPECTRAL REFLECTION FACTORS OF DRY POWDERED PIGMENTS

Wavelength (M_{μ}).	Vermilion.	Venetian Red.	Indian Red.	Raw Sienna.	Yellow Ochre.	Chrome Yellow.	Chrome Green.	Burnt Sienna.	Cobalt Blue.	Ultramarine Blue.
700	0.65	0.32	0.24	0.43	0.59	0.81	0.06	0.25	0.25	0.17
680	0.66	0.32	0.23	0.45	0.59	0.81	0.07	0.24	0.20	0.10
660	0.61	0.30	0.22	0.44	0.59	0.81	0.08	0.23	0.15	0.07
640	0.53	0.28	0.20	0.45	0.60	0.81	0.09	0.21	0.11	0.05
620	0.39	0.24	0.18	0.46	0.61	0.79	0.11	0.20	0.10	0.04
600	0.24	0.19	0.15	0.46	0.64	0.78	0.14	0.18	0.10	0.03
580	0.11	0.12	0.11	0.43	0.63	0.75	0.17	0.14	0.10	0.03
560	0.09	0.07	0.07	0.35	0.53	0.66	0.20	0.09	0.11	0.04
540	0.06	0.06	0.07	0.26	0.42	0.48	0.23	0.06	0.15	0.06
520	0.06	0.05	0.07	0.18	0.32	0.18	0.26	0.05	0.23	0.10
500	0.05	0.05	0.07	0.13	0.24	0.08	0.23	0.04	0.35	0.21
480	0.05	0.05	0.07	0.13	0.21	0.06	0.14	0.04	0.49	0.38
460	0.06	0.05	0.07	0.13	0.20	0.05	0.10	0.04	0.58	0.54
440	0.08	0.05	0.08	0.12	0.20	0.05	0.10	0.04	0.59	0.67

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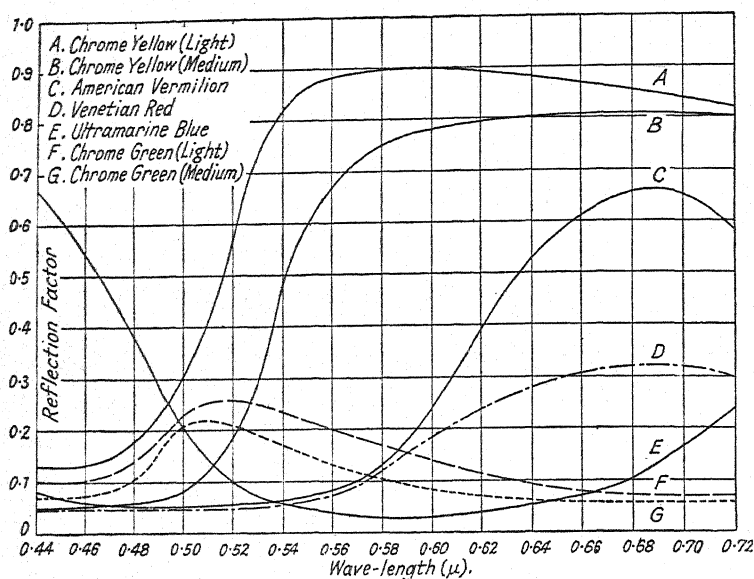


FIG. 52.

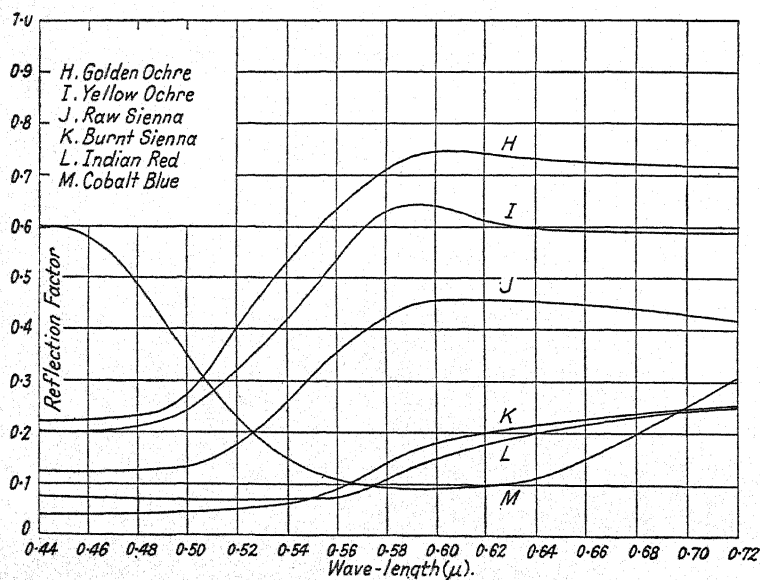


FIG. 53.

TABLE 22

Hue.	Dye.	Spectral Reflection Factors at Extreme Wavelengths ($M\mu$).		
		700.	460.	440.
Blue-green	Malachite Green	0.50		—
Blue-green	Methyl Blue	0.28		—
Green	Brilliant Green (Ethyl Green)	0.64		—
Blue	Victoria Blue	0.73	—	0.52
Blue	Patent Blue	0.78	0.91	0.83

From Table 22 it is evident that dye lakes made from such colours are dangerous to use. Note, for example, that Victoria Blue reflects more red of wavelength 700 $M\mu$ than blue of wavelength 440 $M\mu$. Poster colours are at present being used in studios engaged in making cartoons in colour; and these are made from basic dyes of which the table gives typical examples. Certain of the familiar pigments are safer (Table 23). Should it be required to reproduce a pure blue or green it would be advisable to use the following:

TABLE 23

	Spectral Reflectance. Wave-length in $M\mu$.		
	700.	550.	460.
Winsor Blue	0.0	—	0.71
Emerald Green (arsenite of copper)	0.0	0.87	0.09

Similarly, if it should be desired to reproduce a maximum red, care must be exercised that the chosen pigment does not reflect a band of blue rays; in other words, that the supposed red is not, in fact, a very red cerise, or cardinal red. Certain cheap scenic and poster reds are made from dye lakes which are purplish in hue, although this may not be apparent at first glance.

It is not to be expected that the art director will have instruments available, even in the best-equipped studio, for the measurement of the spectral reflection factors of pigments, nor that he will possess the necessary scientific training which would enable him to use them to advantage, so that recourse must be had to some rough-and-ready

method of examining the spectral reflection factors of a colour. The simplest way is to have three pieces of gelatine filter of the primary tricolour analysis colours (Wratten 25, 58, 47) and to place a small square of the colour to be examined between a strip of white and a strip of black paper. By noting the relative luminosity of the colour through each filter as compared with the white and black, a rough estimate can be made. A still better method, perhaps, is to use a small grey scale such as is available in the *Munsell Book of Color*, published by the Munsell Color Company, Baltimore (distributed by Adam Hilger Ltd., London). A note can then be made as to the position on the grey scale which the test colour matches; this will give a fair indication of its spectral reflection factor in three parts of the spectrum. It will also give a good idea of the density likely to be recorded on each of the three negative records. Such examination of colours is very instructive. We learn, for instance, that many apparently pure hues are very poor reflectors of those parts of the spectrum they reflect most efficiently; because it is clear that for a certain colour to be reproduced with maximum intensity it is essential for the negative to record density equivalent to that which would be obtained from *white*. To reproduce pure red it is necessary to record maximum density through the red filter and to record *nothing* through the green and blue filters. This means that a red to be reproduced as pure as the reproduction colours permit would have to appear to the eye through the three filters as a match to white through the red filter and as indistinguishable from *black* through the green and blue filters.

Reference

- JONES, LOYD A., "The Photographic Reflecting Power of Coloured Objects," *Trans. Soc. Mot. Pic. Eng.*, 11, No. 31 (1927).
Communication No. 327, Kodak Research Laboratories.

3. TRICHROMATIC ANALYSIS

Fundamental Conditions for the Reproduction of Colours by a Three-Colour Process

Almost invariably it has been the practice of writers on the subject of colour photography to introduce their discussion of theory by some reference to the trichromatic theory of colour vision. Unfortunately, this approach has been the origin of much misunderstanding and much unnecessary mystification. In fact, the foundation upon which the whole science of colour photography rests does not require any reference whatever to theories of the functioning of the visual process. The matter is completely covered by the science of colorimetry, the mathematical laws of which are derived from the phenomena of *colour mixture*.

It is a fact that three wavelengths can be selected from the range of visible radiation so that when combined in various proportions they will stimulate nearly the whole range of colour sensation. The colours selected are generally red, green, and blue. Secondly, if two colours are matched in turn by mixtures of three radiations, then the two colours together, when mixed additively by suitable optical means, will be matched by the sum of the two mixtures similarly combined. Upon these two observations colorimetry depends.

Early in the nineteenth century observation of this phenomenon led to Young's hypothesis that the physiological mechanism for light

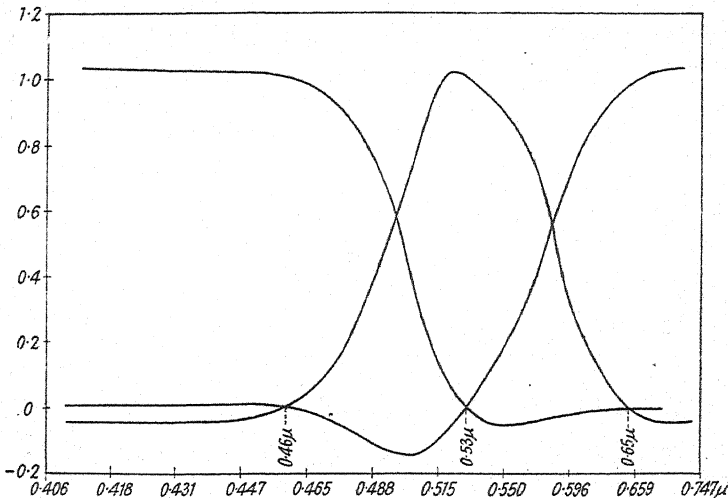


FIG. 54.—Trichromatic mixture curves of spectral primaries 0.650 μ red, 0.530 μ green, and 0.460 μ blue (W. D. Wright).

detection must in all probability include some kind of triple receptor analyser, and recent investigation has provided strong support for the existence of such a function at the retinal stage of the psychophysical chain of events. But it should be noted that *the experimental fact that practically every colour can be matched by the admixture of three colours is independent of any theory of colour vision advanced to account for it.*

It is helpful to conceive of the means of colour photography as constituting a measuring tool for colour. The colour photographic process is subject to the principles of the science of colorimetry. A photographic emulsion is used as a detector (selective) of radiant energy, the selectivity being obtained either by photochemical characteristics of the emulsion or by use of a selective filter modulating the spectral composition of the radiant energy to be recorded.

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Standardization of the colour mixture characteristics of a normal observer and a standard framework for specification were adopted in 1931 by the Commission Internationale de l'Éclairage (C.I.E.). The standard C.I.E. (known in U.S.A. as I.C.I.) observer was based upon mixture data of components consisting of narrow bands of wave-

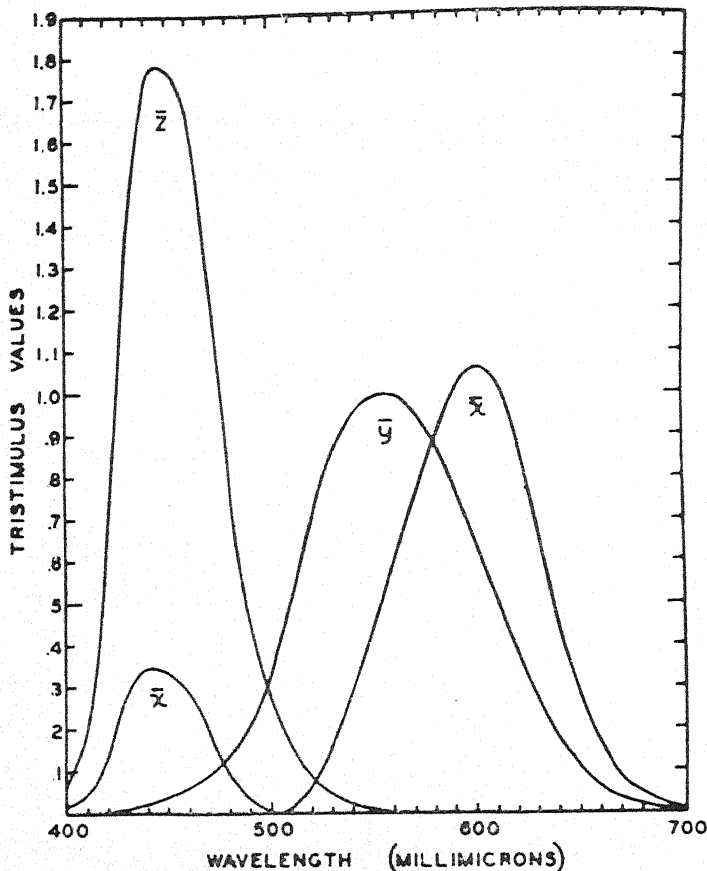


FIG. 55.—Distribution coefficients of the Standard Observer (C.I.E. System) for the spectrum colours. The values of \bar{x} , \bar{y} , \bar{z} are the amounts of the three C.I.E. primaries required to colour match a unit amount of energy having the indicated wavelength.

lengths averaging 650 $M\mu$, 530 $M\mu$, and 460 $M\mu$. These data were determined by W. D. Wright, D.Sc., of the Imperial College of Science and Technology, and independently by J. Guild of the National Physical Laboratory (Great Britain). Both data corresponded extremely closely (Fig. 54). The C.I.E. trichromatic system of colour specification employs three reference stimuli which are imaginary and are

linearly transformed from the data based on real stimuli having mathematical significance only, in which negative values (in the real stimuli) have been eliminated and one curve of the three, namely the green, is made identical to the spectral visual sensitivity function. These

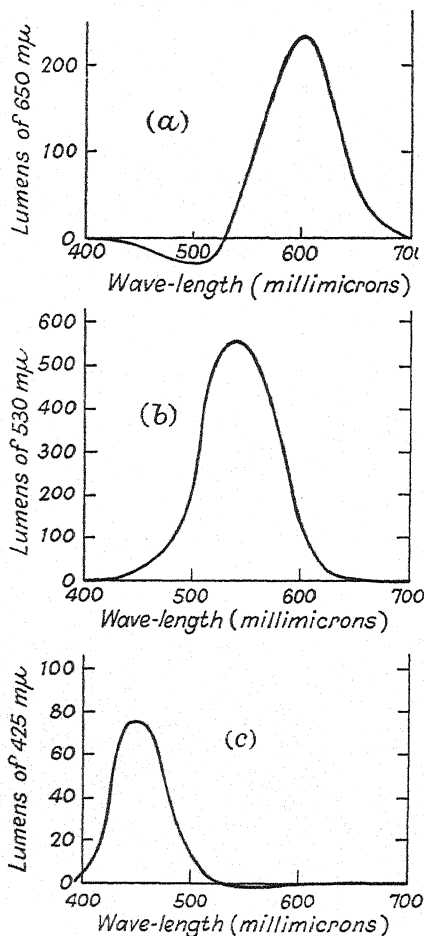


FIG. 55A.—Colour mixture curves using real reference primaries. (R.G.B. Distribution coefficients.)

data can be used to calculate accurately all stages of the transformations which take place in the recording and reproduction processes of colour photography (Fig. 55).

It has been shown by G. B. Harrison and R. G. Horner [2] that a perfect colour process would have to reproduce a spectrum perfectly. Equations can be developed which will give for any specified emulsion

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sensitivity the form of the theoretically ideal taking filters for any given set of viewing filters (Figs. 56A, 56B, 56C), but negative values¹ are obtained for the transmission in certain regions for the spectrum,

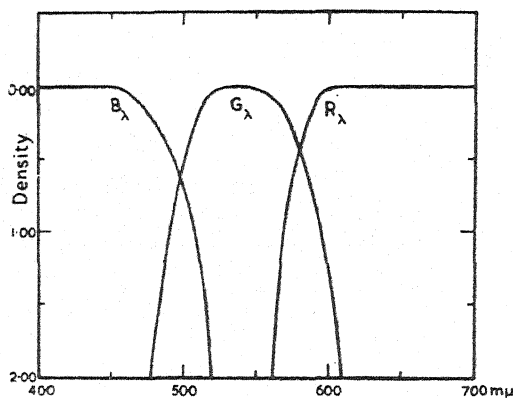


FIG. 56A.—Optimum combined taking and viewing filters for use with an emulsion of spectral sensitivity shown in Fig. 56B (Harrison and Horner).

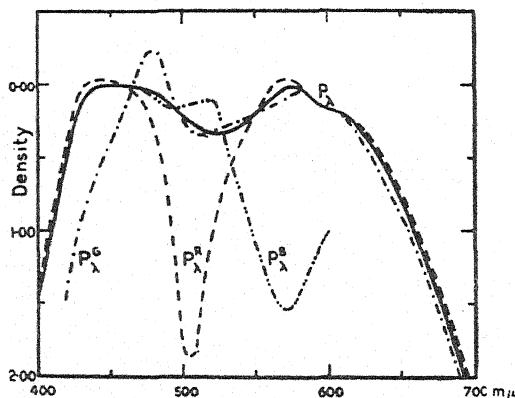


FIG. 56B.—Optimum emulsion spectral sensitivity for use with the filters shown in Fig. 56A (Harrison and Horner).

and as a filter obviously has only positive transmissions, it follows that exact reproduction of all colours is impossible by any three-colour additive process (Figs. 56D and 56E), just as it is impossible to match all spectrum colours by admixture of three monochromatic primaries.

¹ A negative amount of a primary is obtained by transferring the primary to the opposite side of the divided field of a colorimeter, where it is combined with the radiation whose tristimulus values are being determined.

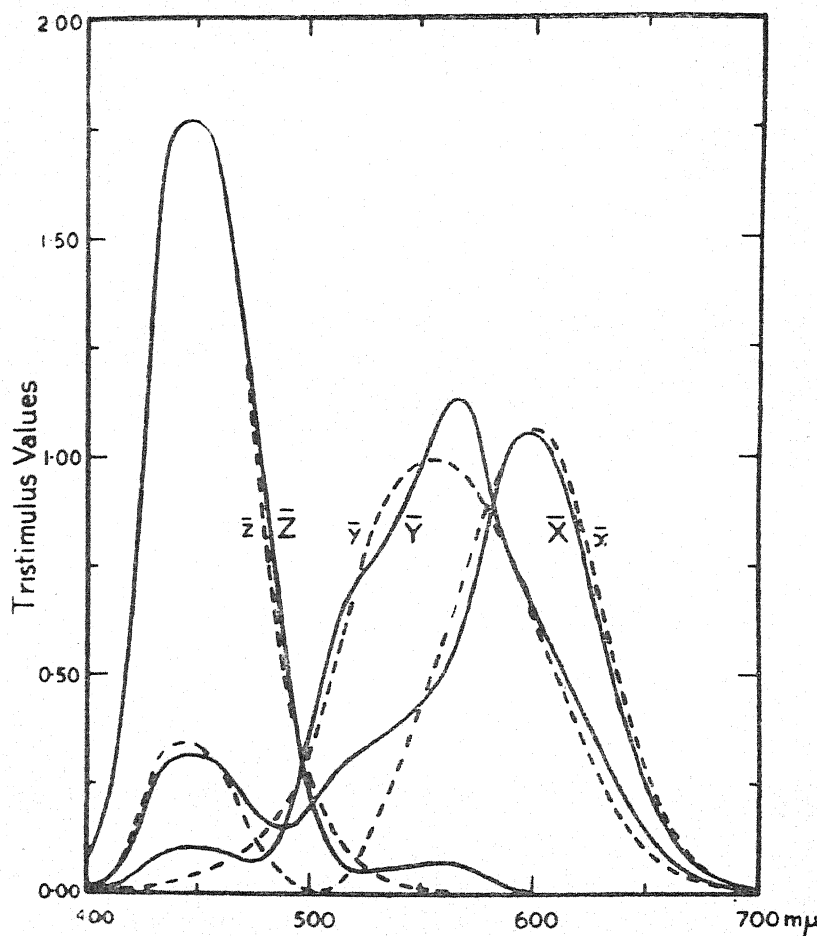


Fig. 56C.—Theoretical reproduction of monochromatic colours by a process using the filters and emulsion sensitivity shown in Figs. 56A and 56B (Harrison and Horner).

In fact, the equations obtained are the distributive coefficients of an equal energy spectrum, with the viewing filters taken as unitary stimuli. Thus in the case of an additive transparency:—

$$\begin{aligned}
 & \left(\begin{array}{c} \text{Spectral dis-} \\ \text{tribution of} \\ \text{the colour} \\ \text{reproduction} \end{array} \right) = \\
 & \left(\begin{array}{c} \text{Transmission} \\ \text{factor of} \\ \text{silver behind} \\ \text{red filter} \end{array} \right) \left(\begin{array}{c} \text{Relative intensity} \\ \text{of light behind red} \\ \text{filter or area of} \\ \text{red element} \end{array} \right) \left(\begin{array}{c} \text{Spectral dis-} \\ \text{tribution of} \\ \text{the viewing} \\ \text{red filter} \end{array} \right) + \left(\begin{array}{c} \text{Ditto for green} \\ \text{and ditto for} \\ \text{blue} \end{array} \right) \\
 & \text{or } T_{\lambda} = t_{R} a_{R} R_{\lambda} + t_{G} a_{G} G_{\lambda} + t_{B} a_{B} B_{\lambda}
 \end{aligned}$$

COLOUR CINEMATOGRAPHY

Prof. A. C. Hardy of Massachusetts Institute of Technology has determined the characteristics of recording tricolour filters which would provide negatives to modulate reproduction primaries at every point in the reproduction [3].

Say that the light incident upon the camera lens originating from a

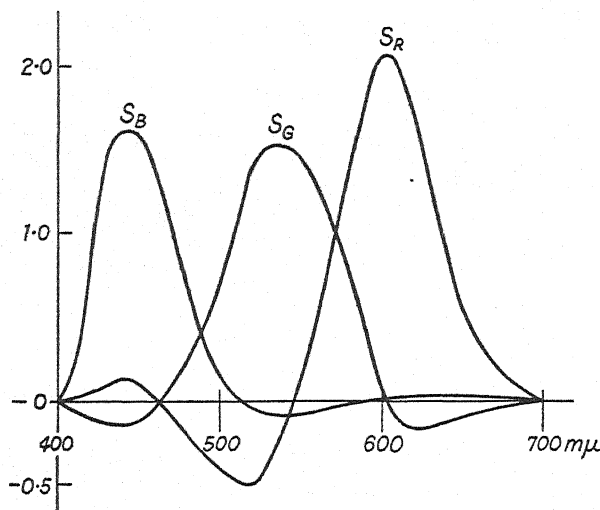


FIG. 56D.—Theoretical spectral sensitivities for a typical additive process (G. B. Harrison).

given area of the subject has a spectral energy distribution E . The trichromatic co-ordinates will be

$$X = \int_0^{\infty} E\bar{x}d\lambda, \quad (1a)$$

$$Y = \int_0^{\infty} E\bar{y}d\lambda, \quad (1b)$$

$$Z = \int_0^{\infty} E\bar{z}d\lambda, \quad (1c)$$

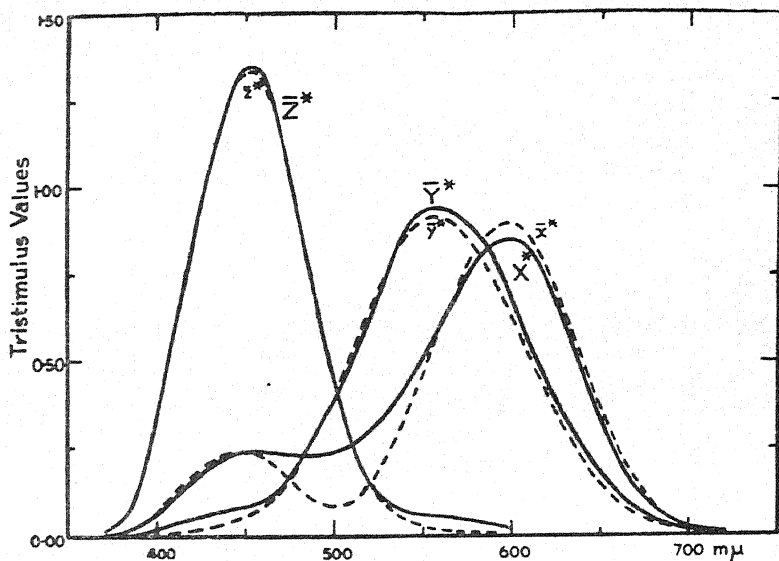
where \bar{x} , \bar{y} , \bar{z} are the distribution coefficients of unit amounts of the spectral colours in the colorimetric system used.

Suppose the tristimulus values of unit amounts of the primaries that are mixed to provide the reproduction position are X_r , Y_r , Z_r , X_g , Y_g , Z_g , and X_b , Y_b , Z_b , respectively. Then, if an area of the reproduction contains r units of the red primary, g of the green, and b of the blue, the trichromatic co-ordinates of this area are

$$X' = rX_r + gX_g + bX_b, \quad (2a)$$

$$Y' = rY_r + gY_g + bY_b, \quad (2b)$$

$$Z' = rZ_r + gZ_g + bZ_b. \quad (2c)$$



Theoretical reproduction of 60 $M\mu$ band by a process using the filters and emulsion sensitivity shown in Figs. 56A and 56B (Harrison and Horner).

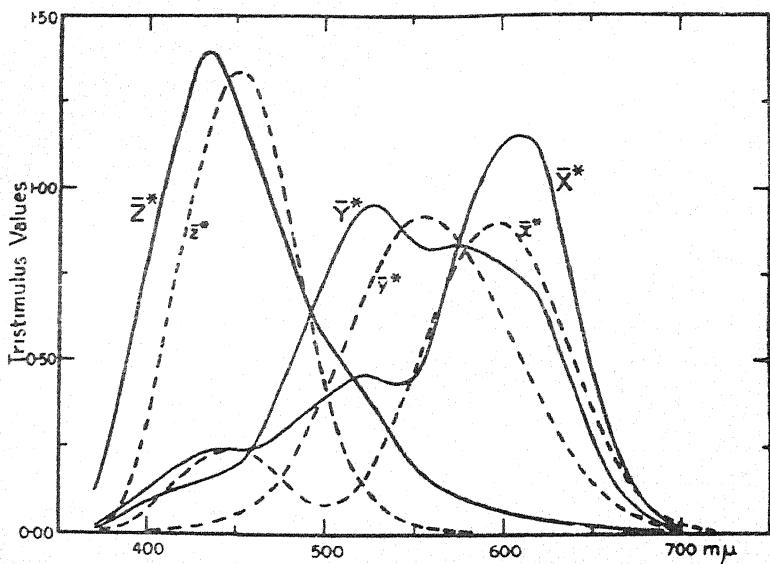


FIG. 56E.—Theoretical reproduction of 60 $M\mu$ band by a typical commercial process (Harrison and Horner).

If this area is to evoke the same visual sensation as the area of the subject characterized by the energy distribution E , the necessary condition is

$$X' = X, \quad (3a)$$

$$Y' = Y, \quad (3b)$$

$$Z' = Z. \quad (3c)$$

Over a wide range of luminance level the reproduction would be entirely satisfactory if the tristimulus values of the reproduction were proportional, but not necessarily equal, to those of the corresponding area of the original.

Let the effective spectral sensitivities of the three negative emulsions be represented by S_r , S_g , and S_b respectively, then when exposed to spectral energy distribution E the three exposures are proportional, respectively, to

$$\Sigma_r = \int_0^\infty ES_r d\lambda, \quad (4a)$$

$$\Sigma_g = \int_0^\infty ES_g d\lambda, \quad (4b)$$

$$\Sigma_b = \int_0^\infty ES_b d\lambda. \quad (4c)$$

Each exposure determines the amount of the reproduction primaries. If the conditions for tone reproduction are satisfied,

$$r = k_r \Sigma_r, \quad (5a)$$

$$g = k_g \Sigma_g, \quad (5b)$$

$$b = k_b \Sigma_b. \quad (5c)$$

These five sets of equations may be combined algebraically to yield the following equations:

$$k_r X_r \int_0^\infty ES_r d\lambda + k_g X_g \int_0^\infty ES_g d\lambda + k_b X_b \int_0^\infty ES_b d\lambda = \int_0^\infty E \bar{x} d\lambda, \quad (6a)$$

$$k_r Y_r \int_0^\infty ES_r d\lambda + k_g Y_g \int_0^\infty ES_g d\lambda + k_b Y_b \int_0^\infty ES_b d\lambda = \int_0^\infty E \bar{y} d\lambda, \quad (6b)$$

$$k_r Z_r \int_0^\infty ES_r d\lambda + k_g Z_g \int_0^\infty ES_g d\lambda + k_b Z_b \int_0^\infty ES_b d\lambda = \int_0^\infty E \bar{z} d\lambda. \quad (6c)$$

These define the essential conditions for correct reproduction of one of the subject colours. Inspection of these equations reveals that one subject colour is correctly reproducible in an infinite number of ways. In other words, regardless of the form of the emulsion filter sensitivities S_r , S_g , and S_b , or the tristimulus values of the reproduction primaries, the constants may always be chosen in such a manner that equations 6 will be satisfied for a given colour in the subject.

To reproduce all colours, equations 6 must be satisfied simultaneously, regardless of the form of the function E (spectral distribution of energy of original colour). This would be true if at every wavelength,

$$k_r X_r S_r + k_g X_g S_g + k_b X_b S_b = \bar{x}, \quad (7a)$$

$$k_r Y_r S_r + k_g Y_g S_g + k_b Y_b S_b = \bar{y}, \quad (7b)$$

$$k_r Z_r S_r + k_g Z_g S_g + k_b Z_b S_b = \bar{z}. \quad (7c)$$

Only relative values of S_r , S_g , and S_b are required in practice, so that equations 7 can be written more simply in terms of the trichromatic coefficients of the reproduction primaries rather than in terms of their tristimulus values. Then the fundamental conditions for exact colour reproduction by a tricolour process become

$$x_r S_r + x_g S_g + x_b S_b = \bar{x}, \quad (8a)$$

$$y_r S_r + y_g S_g + y_b S_b = \bar{y}, \quad (8b)$$

$$z_r S_r + z_g S_g + z_b S_b = \bar{z}. \quad (8c)$$

Hardy notes that "these conditions are perfectly general in the sense that the colours of the subject may be either real or imaginary. Likewise the reproduction primaries may be either real or imaginary. In a practical process the reproduction primaries are real, and negative amounts of the primaries cannot be employed. This *limits* the realizable colour gamut, but in no way alters the fundamental requirements which must be fulfilled by any three-colour process, real or imaginary."

It is relatively easy to apply equations 8 to additive processes, but not so easy in the case of subtractive processes. In an ideal subtractive process each dye absorbs radiation uniformly in a spectral region not absorbed by the other two, so that a reproduction primary is determined by the colour of the light absorbed by one of the three dyes. By substituting the values of the reproduction primaries in equations 8, the spectral sensitivities of the colour-separation negatives can be calculated.

In subtractive processes one dye only is not actively absorbent at every wavelength. A composite subtractive primary can be determined by taking into consideration the absorption contribution at all wavelengths of the three dyes combined. Hardy determines such primaries by starting with the spectral transmittance of a piece of film whose colour is, say, a light flesh tint when projected (curve F in Fig. 57). He then takes another piece in which the concentration of the red-absorbing (cyan) dye is slightly reduced (curve R). Assuming a projection source corresponding to illuminant C, the tristimulus values calculated from curves R', G', and B' of Fig. 57 are shown in Table 24.

TABLE 24

<i>Red Primary.</i>	<i>Green Primary.</i>	<i>Blue Primary.</i>
$X_r = 0.4969$	$X_g = 0.1985$	$X_b = 0.1847$
$Y_r = 0.3346$	$Y_g = 0.4423$	$Y_b = 0.1265$
$Z_r = 0.1685$	$Z_g = 0.3592$	$Z_b = 0.6889$

Substituting these values in equations 8, the values of S_r , S_g , and S_b are those shown in Fig. 58. Naturally, we have negative values for these emulsion responses, and these can be effectively obtained only by masking.

Hardy continues the argument thus: "Three negatives may be

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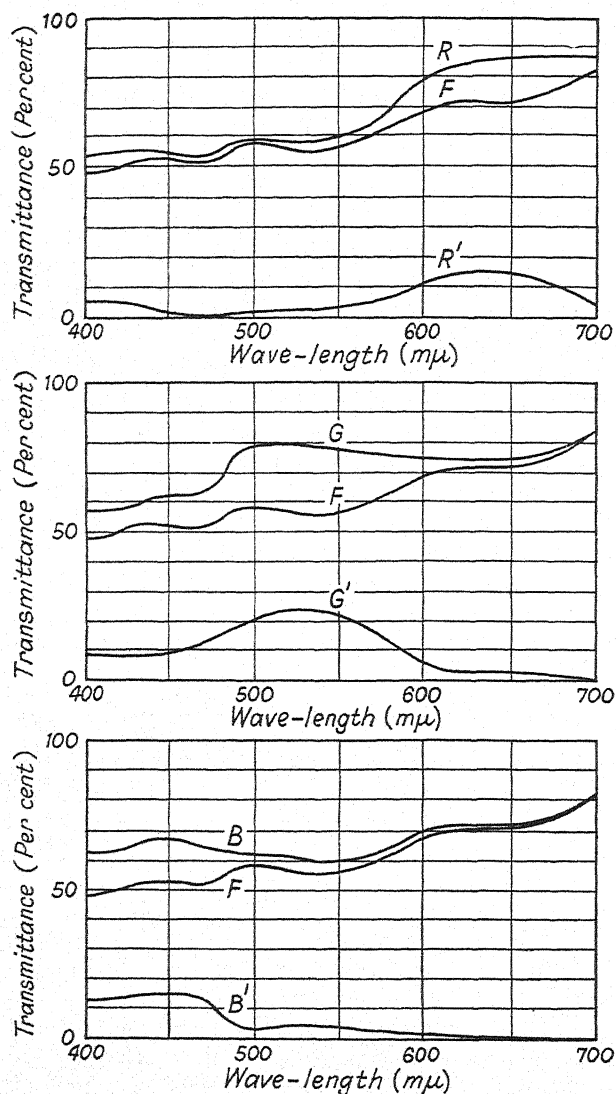


FIG. 57.—These spectrophotometric curves illustrate a method by which the reproduction primaries in a subtractive process can be identified (A. C. Hardy).

made to suffice by abandoning the assumption incorporated in equations 5. Instead, let it be assumed that the amount of the red primary is to be made dependent to some extent upon the exposure received by all three-colour separation negatives. If a similar assumption is

THE THEORETICAL BASIS

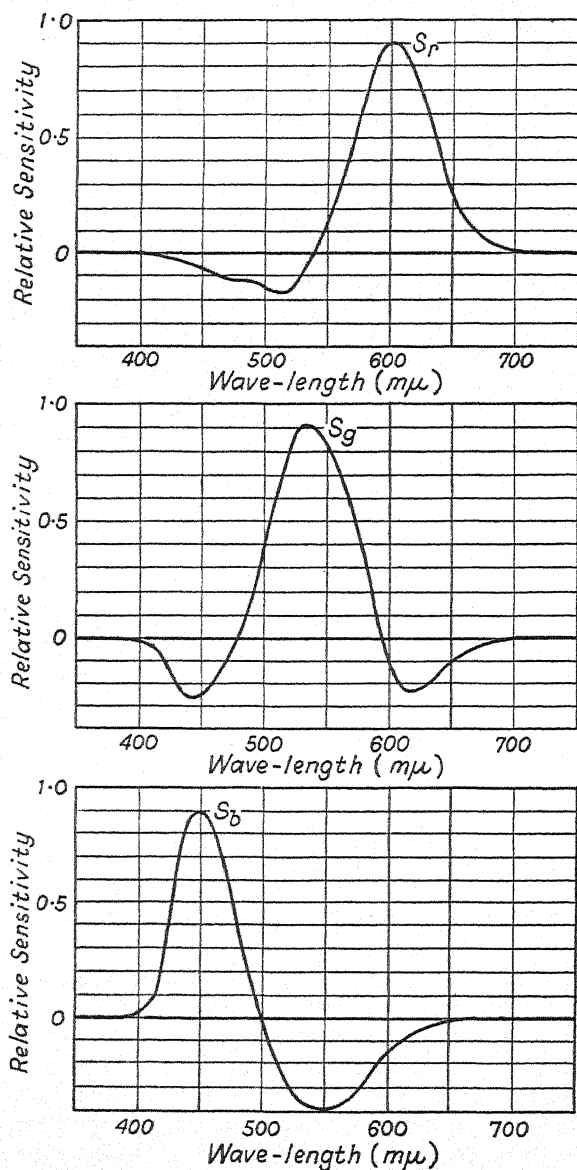


FIG. 58.—These curves indicate the relative spectral sensitivity of the three emulsions to be used in making three-colour separation negatives that will control properly the reproduction primaries identified in Fig. 57 (A. C. Hardy).

made with respect to the green and blue primaries, equations 9 are an expression of the proposed technique "

$$r = k_1 \Sigma_r + k_2 \Sigma_g + k_3 \Sigma_b, \quad (9a)$$

$$g = k_4 \Sigma_r + k_5 \Sigma_g + k_6 \Sigma_b, \quad (9b)$$

$$b = k_7 \Sigma_r + k_8 \Sigma_g + k_9 \Sigma_b. \quad (9c)$$

To realize this in practice involves controlling the red primary by means of an image that is a composite record of the red, green, and blue negatives. The extent to which each exposure is weighted by this record is determined by the magnitude of the constants k_1 , k_2 , and k_3 . When one of the constants is less than zero, a positive image rather than a negative image is to be employed in making the composite record. Care must also be taken that the characteristics of the photographic materials are substantially linear in order that a true addition or subtraction of exposures may be effected.

To quote Hardy: "With this understanding of the proposed technique, let equations 9 be substituted in the previous development instead of equations 5. The conditions for correct colour rendering are then found to take the form

$$K_1 S_1 + K_2 S_2 + K_3 S_3 = \bar{x}, \quad (10a)$$

$$K_4 S_1 + K_5 S_2 + K_6 S_3 = \bar{y}, \quad (10b)$$

$$K_7 S_1 + K_8 S_2 + K_9 S_3 = \bar{z}, \quad (10c)$$

where the constants in the above equations (indicated by capital letters) have the following values:

$$\begin{aligned} K_1 &= k_1 X_r + k_4 X_g + k_7 X_b \\ K_2 &= k_2 X_r + k_5 X_g + k_8 X_b \\ K_3 &= k_3 X_r + k_6 X_g + k_9 X_b \\ K_4 &= k_1 Y_r + k_4 Y_g + k_7 Y_b \\ K_5 &= k_2 Y_r + k_5 Y_g + k_8 Y_b \\ K_6 &= k_3 Y_r + k_6 Y_g + k_9 Y_b \\ K_7 &= k_1 Z_r + k_4 Z_g + k_7 Z_b \\ K_8 &= k_2 Z_r + k_5 Z_g + k_8 Z_b \\ K_9 &= k_3 Z_r + k_6 Z_g + k_9 Z_b \end{aligned}$$

Hardy concludes his beautiful analysis thus: "Equations 10 are of the same form as equations 7, and can be used in the same manner. In this case the spectral sensitivities, S_r , S_g , and S_b , may be everywhere positive and are therefore readily realizable in practice. Those familiar with the concepts of colorimetry will recognize that this technique involves, in effect, the preparation of a set of three negatives which would properly control the reproduction primaries employed in any process, additive or subtractive. In the application of this technique to subtractive processes, the number of constants is so great that the reproduction may arbitrarily be made correct at several points within the boundaries of the realizable colour solid.

"It may be added by way of conclusion that the requirements of the theory herein set forth are inescapable. They are the direct consequence of the characteristics of the visual processes of the human

observer. No three-colour process can ever duplicate the energy distribution of each point of the subject, but it can be made to duplicate the visual effect, provided the necessary conditions are satisfied. That the conventional colour separation negatives do not properly control the reproduction primaries has been given tacit recognition by the empirical attempts at 'correction' such as *masking*. Although such methods of correction are incapable of satisfying the conditions for perfect colour reproduction, the improvement resulting from their

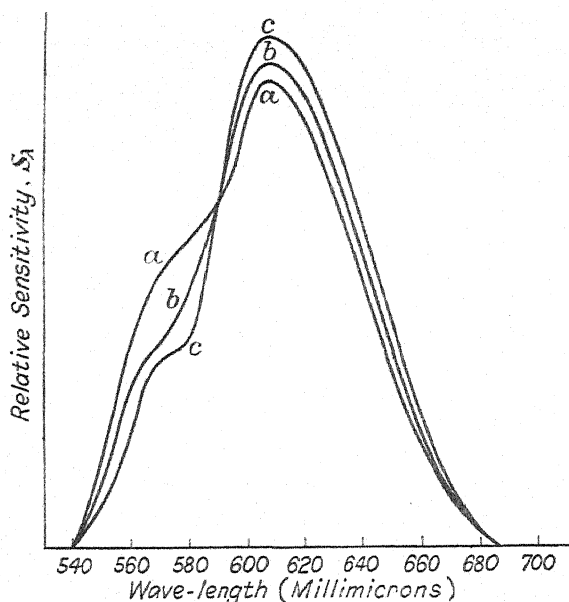


FIG. 59.—Variation of a relative spectral sensitivity (as a function of density) for a certain emulsion and filter combination (G. B. Harrison).

use seems to indicate the desirability of employing the type of correction that a rigorous analysis of the problem prescribes."

NOTE.—The writer has endeavoured to do Prof. Hardy's classic paper justice, apologizing for such abridgements as were dictated by restrictions of space.

Similarly, MacAdam and others have shown that the achievement of perfect reproduction of not only the relative luminance but also the dominant wavelength and purity of every detail in the subject photographed is theoretically unobtainable unless the spectral sensitivity curves of the emulsions used for trichromatic analysis are in quantitative agreement with curves which specify the colour-matching properties of normal human vision. These spectral sensitivities should be linear

combinations of the colour mixture functions. The required photographic sensitivity curves will depend on the chromaticities of the reproduction primaries. The negative portions of these curves correspond approximately in magnitude and spectral location to the locations of the portion of the colour mixture diagram lying within the spectrum locus, but outside the triangle, which represent the reproduction primaries. Unfortunately, the contrast characteristics of an emulsion vary with wavelength, with consequent variations of spectral sensitivity with exposure (Fig. 59). Only when emulsions can be made having contrast characteristics independent of wavelength will it be possible to design filters which will render the response of the emulsion equivalent

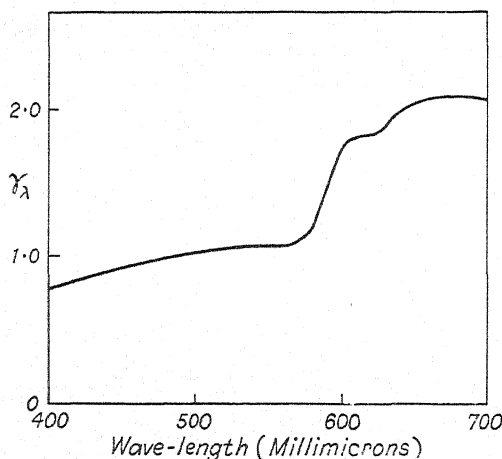


FIG. 59A.—Contrast (γ) versus wavelength characteristics of a certain panchromatic material (G. B. Harrison).

to that of the eye for all normal levels of illumination. Sets of filters can be used whose transmittances closely resemble the positive portions of the colour mixture functions. A negative made with such filters is called the *principal negative*.

Another filter combination can be chosen to provide relative spectral sensitivities proportional to the values of the negative portions of the mixture curves. This negative is known as a *correction negative*. A positive transparency printed from this negative is known as a *mask*. The principal negative and the mask are finally superimposed in register to form what MacAdam has called a *corrected separation negative*. The masking method has been shown by mathematical analysis to be superior to normal separations. Computations show that little improvement can be effected by any of the methods which have been suggested for improving normal colour separations in which

the spectral sensitivities are proportional to the positive portion only of the tristimulus values of the spectrum computed on the basis of the actual projection primaries. We must distinguish, however, between theoretically perfect photographic methods for obtaining perfect reproductions and the methods which are feasible in commercial practice.

MacAdam [4] has discussed also the theoretical basis for a law of subtractive mixture analogous to the accepted methods for computing additive mixtures. From this law calculations show that in the case of the dyes used in the wash-off relief process the masks would have to be prepared as follows:

A positive mask made from the green camera negative is registered with the red camera negative to form the cyan printer. This mask should have a gradient of 0.42 with relation to the green camera negatives. A positive mask from the red camera negative should be registered with the green camera negative to form the magenta printer. This should have a gradient of 0.58 with respect to the red camera negative. Finally, a positive mask from the green camera negative should be registered with the blue camera negative for the yellow printer. Normally the mask made from the green negative can be used for both the cyan and yellow printers. Thus, only two masks need be made.

It is not proposed in this treatise to present a résumé of the immense literature which has accumulated in the last few years covering the theoretical mathematical treatment of the problems of colour photography. Those aspects of the science of colorimetry with which the serious student must acquaint himself in order to master the subject are fully dealt with in the works cited under the references given below.

Tricolour Filter Ratios

We know that the densities of the image of a scale of greys obtained through each of the three filters must be identical. The ratio of exposure will vary for a given set of filters and for different makes of film, and also with the spectral character of the light-source. The principal manufacturers supply correct exposure ratios. It is, however, advisable to test the balance obtained under any particular set of conditions. In the case of a beam-splitter camera this is essential, as the light reaching each primary filter will depend upon the design of a special optical beam-dividing unit.

Perhaps the simplest method is to place a patch of the filter in direct contact with the film and to take an exposure with the lens facing a surface of diffusely reflecting white. For this purpose "pot opal" glass, backed by white drawing paper, makes a satisfactory reflector.

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We might obtain the following densities using Kodak Super-X Motion Picture Negative Film at a given exposure:

<i>Wratten Filter No.</i>					<i>Daylight Illumination (Sunlight).</i>	<i>Tungsten Lamp (3,000° K.)</i>
25	..	..	..	..	Density 1.14	1.33
58	..	..	..	..	„ 1.08	1.11
47	..	..	..	..	„ 1.11	1.03

Developing the film to a gamma of, say, 0.65, it will be seen that for this particular film the compensation required is very little. Taking the green as the lowest and compensating for red and blue, we have:

$$1.14 - 1.08 = 0.06 \quad \frac{0.06}{0.65} = 0.0921$$

$$1.11 - 1.08 = 0.03 \quad \frac{0.03}{0.65} = 0.046$$

Now these figures really represent excess densities obtained, and since density is proportional to the log. of exposure, their antilogs. represent the factors by which the effective exposure is in excess. Hence the figures may also be regarded as representing densities which must be added to the filters to reduce the effective exposures, while the reciprocals of the antilogs. represent the factors by which the exposures (*e.g.*, the areas of the filters) must be reduced.

Now the antilog. of 0.092 is 1.236 (additional density for red), and the antilog. of 0.046 is 1.11 (additional density for blue). The reciprocals are 0.809 and 0.901 respectively, or expressed as percentages the red and blue filters must be reduced to 80.9 and 90.1 per cent. respectively of their original areas.

Correction for Tungsten Light

This time the blue is the lowest and we correct for red and green.

For red,

$$1.33 - 1.03 = 0.3 \quad \frac{0.3}{0.65} = 0.46 \text{ (added density).}$$

For green,

$$1.11 - 1.03 = 0.08 \quad \frac{0.08}{0.65} = 0.123 \text{ (added density).}$$

Antilogs. of 0.46 and 0.123 are respectively 2.88 and 1.33.

Reciprocals of these are 0.3472 and 0.752.

Hence red and green filters have to be reduced to 34.7 and 75.2 per cent. of original areas respectively.

Now it should be simple to get from these figures the required compensation to convert perfect daylight filters to perfect ones for tungsten. Thus, using the corrections determined above, the filter areas for equal densities are:

THE THEORETICAL BASIS

					<i>Daylight.</i>	<i>Tungsten.</i>
R.	..	..	..	..	80.9	34.7
G.	..	..	..	..	100	75.2
B.	..	..	..	..	90.1	100

Equalizing for blue, we have:

					<i>Daylight.</i>	<i>Tungsten.</i>
R.	..	..	..	..	90	34.7
G.	..	..	..	..	111	75.2
B.	..	..	..	..	100	100

Hence, to change from daylight to tungsten, the red area has to be reduced from 90 to 34.7, which works out as a reduction to 38.6 per cent. of original area. Similarly the green is reduced from 111 to 75.2—i.e., to 68 per cent.

Entirely satisfactory tricolour filters are manufactured by the leading photographic firms, such as Kodak, Ilford, Dufay-Chromex, and Ansco. The relative spectral transmittances of these filters differ only in minor respects. Ilford Ltd. supply sets of compensated filters which give correctly balanced exposure for the grey scale when used with panchromatic and hypersensitive panchromatic materials. These filter sets consist of the existing standard trichromatic blue filter, whereas the green and red filters have been made by dyes which have been mixed with a certain proportion of neutral grey. Such filters obviate the necessity for calculating filter ratios.

For two-colour work with bipack it is generally unnecessary to use a filter. On occasions it may be desirable to use a K-1 or K-2 (Wratten) or a *Beta* or *Gamma* Ilford Filter for exterior work. When using bipack for tricolour work by alternate exposures the best pair of filters is Wratten No. 12 and No. 47 for artificial light and No. 15 and No. 49 for sunlight.

Two-colour filters for additive work are:

TAKING FILTERS: SUNLIGHT

Wratten No. 28 (Red-orange).

Wratten No. 40A (Blue-green).

TAKING FILTERS: TUNGSTEN LAMP (3,500° K.)

Wratten No. 28.

Wratten No. 56 or No. 40.

PROJECTION FILTERS

Wratten No. 23B.

Wratten No. 69.

FILTER CALCULATIONS FOR TRICHROMATIC ANALYSIS

S. H. Groom, of the staff of the Science Museum, London, has made some interesting calculations of the filter-balance problem, and the following material is included with his kind permission.

On first consideration it might appear that if a given combination of filters and emulsion gives correct results for one type of illumination, it would do so for all others. For it may be argued that a change in the composition of the illuminant will affect equally both the eye and the photographic record. If we really desired to reproduce what we actually see, this would appear to be the case. In point of fact, however, the eye tends to accept a grey pigment as grey under widely different conditions of illumination and to adjust its whole colour scale accordingly. In any case, practical experience shows that it is normally desirable and in fact necessary to "balance" the three negatives so that they give equal densities when a grey pigment is photographed with the illuminant in question.

In the balancing process the principal factors involved are (a) the spectral composition of the light, (b) the transmission characteristics of the filters, and (c) the sensitivities of the emulsion for red, green, and blue.

Of these three it is usually much easier to adjust the values of (b) than of (a) or (c), and hence in practice we usually choose filters which are approximately correct for a given illuminant and a given emulsion and then compensate them (*e.g.*, by reduction in area or addition of density) to give equal densities for a grey scale.

For a different illuminant we may either choose different filters or, in some cases, use the same filters with different compensation. In this way various types of arithmetical problems arise which are extremely simple in themselves but in which mistakes are easily made unless the principles are clearly understood and unless a nomenclature is used which avoids ambiguity.

It should be remarked that in problems of colour photography we are not usually concerned with actual values in definite units so much as with the *ratio* of the quantities concerned, such as intensity, sensitivity, etc., for each of the three primaries red, green, and blue. Such groups of three numbers are frequently expressed as percentages—*i.e.*, so that they add up to 100—but when we are concerned with a ratio there is no particular virtue in this, and in the course of calculations it is a sheer waste of time to reduce to percentages, at any rate before reaching the final ratio which is being sought.

Before discussing problems of the type referred to it will clearly be necessary to define the various terms to be used:

The *Relative Intensities* of red, green, and blue in a given illuminant

are expressed as the ratio of the amounts of energy contained in the three wavelength bands used in colour photography. This ratio could be obtained from an energy distribution curve of the illuminant by determining the areas under the three portions of the curve in question. Intensities will be denoted by I , I_R , I_G , I_B , etc.

The *Transparency* of a filter is defined as the ratio of the intensity of the transmitted light to that of the incident light. Thus, if light of intensity I_1 falls on a filter and I_2 is transmitted,

$$\text{Transparency} = \frac{I_2}{I_1}.$$

By the *Relative Transparencies* $T_R : T_G : T_B$ of a set of tricolour filters we shall mean the ratio of their transparencies for light of their own colour. Note that, since each filter transmits light of its own colour only, the transparency of each filter for an equal energy illuminant would be one-third of its transparency to light of its own colour. Hence, since all three transparencies would be reduced in the same ratio, we might have defined *relative* transparencies as the ratio of the intensities transmitted by the filters when a "white" light of the same intensity was incident on all three filters. Actual transparencies can, of course, never be greater than 1, but this will clearly not apply to numbers which we may use to represent relative transparencies.

Opacity is defined as the reciprocal of transparency—i.e., as $\frac{I_1}{I_2}$.

Note that if one filter has a transparency $1/3$ and another a transparency $1/2$, the two together will transmit $1/3$ of $1/2$ of the incident light and the transparency of the pair together is $1/6$. In general, the transparency of any combination of filters may be found by *multiplying* together the individual transparencies. Similarly, the opacity of a combination of filters equals the *product* of the individual opacities.

Density is defined as \log . (opacity). Since the \log . of a product equals the sum of the \log s. of the factors, to obtain the density of a combination of filters we must *add* the separate densities.

The terms "density" and "opacity" should not be confused. At the same time it is obvious that when the opacities are equal the densities are also equal, so we can speak of filters or negatives of equal density or of equal opacity without ambiguity.

Relative Sensitivities $S_R : S_G : S_B$ will be defined as the ratio of the photographic effect given by equal intensities of R, G, and B, other things being equal, or as the ratio of the reciprocals of the intensities required to give equal densities.

We are now in a position to consider certain types of problem involving some of the above factors.

Relative Transparencies

(1) Given an illuminant of equal intensities for R, G, and B, and given the relative sensitivities of the emulsion, to determine the required relative transparencies of the filters to give equal densities for a grey scale.

For this the values of $S \times T$ must be equal for R, G, and B.

Hence the values of T must be inversely proportional to those of S .
Hence

$$T_R : T_G : T_B \text{ must equal } \frac{1}{S_R} : \frac{1}{S_G} : \frac{1}{S_B}$$

For example, if the sensitivities are 6 : 30 : 64, the transparencies must be $1/6 : 1/30 : 1/64 = 160 : 32 : 15$. (If reduced to percentages, this becomes 77.3 : 15.5 : 7.25.)

(2) Given the relative intensities of the illuminant and the relative sensitivities of the emulsion, to find the required relative transparencies of filters to give equal densities for a grey scale.

The values of $I \times T \times S$ must be equal for R, G, and B.

Hence the values of T must be inversely proportional to those of $I \times S$ —i.e.,

$$T_R : T_G : T_B \text{ must equal } \frac{1}{I_R S_R} : \frac{1}{I_G S_G} : \frac{1}{I_B S_B}$$

For example, suppose the relative intensities are 60 : 27 : 13 and the relative sensitivities 6 : 30 : 64, then

$$\begin{aligned} T_R : T_G : T_B &= \frac{1}{60 \times 6} : \frac{1}{27 \times 30} : \frac{1}{13 \times 64} \\ &= 936 : 416 : 405 \end{aligned}$$

or, expressed as percentages, 53.2 : 23.7 : 23.05.

(3) Given the desired relative transparencies (t) for an illuminant of known relative intensities (i), to find the required relative transparencies (T) for another illuminant of known relative intensities (I) used with the same emulsion (of unknown relative sensitivities).

Since the emulsions are the same in both cases, the transparencies must be inversely proportional to the relative intensities.

Hence

$$T_R : T_G : T_B = t_R \times \frac{i_R}{I_R} : t_G \times \frac{i_G}{I_G} : t_B \times \frac{i_B}{I_B}$$

For example, suppose the relative transparencies 70 : 20 : 10 give equal densities for grey with an illuminant of relative intensities 50 : 30 : 20, then, using the same emulsion, the required relative transparencies for an illuminant 60 : 25 : 15 will be given by

$$\begin{aligned} T_R : T_G : T_B &= 70 \times \frac{50}{60} : 20 \times \frac{30}{25} : 10 \times \frac{20}{15} \\ &= 175 : 72 : 40 = 61 : 25 : 14 \text{ (approx.).} \end{aligned}$$

The Compensation of Filters

There are two principal methods of compensating filters:

- (1) By the reduction of area.
- (2) By the addition of density.

(1) To reduce the total transmission of a filter from a value T_1 to a value T_2 we need only reduce the area in the same proportion.

If the problem occurs in connection with three filters, we proceed as follows:

Suppose the relative transmissions are 60 : 24 : 16 for R, G, and B respectively, and we require a ratio 40 : 32 : 28. Multiplying the latter throughout by 16/28, it reduces to 22.8 : 18.3 : 16 (equalizing for blue).

From this we see that the red filter must be reduced to $\frac{22.8}{60}$ (=38 per cent.) of its original area and the green filter to $\frac{18.3}{24}$ (=76.2 per cent.) of its original area.

(2) To compensate by the addition of density.

If we require to change a filter of transparency T_1 to one of transparency T_2 , we could obviously add a filter of transparency T such that $T \times T_1 = T_2$ —i.e., such that $T = \frac{T_2}{T_1}$. The opacity of such a filter would be $\frac{T_1}{T_2}$, and its density would be

$$\log. \frac{T_1}{T_2} = \log. T_1 - \log. T_2.$$

Suppose, for example, that we wished to solve the previous example by the addition of densities, we first equalize for the blue filter as before. Then:

Required additional density for the red filter=

$$\log. 60 - \log. 28 = 1.7782 - 1.4472 = 0.331.$$

Similarly, for the green,

$$\log. 24 - \log. 18.3 = 1.3802 - 1.2625 = 0.1177.$$

Note also that the antilog. of density gives opacity and the reciprocal of this gives transparency. Hence the addition of a density, D , to a filter of transparency, T , gives a filter of

$$\text{Transparency } T \times \frac{1}{\text{Antilog. } D}.$$

*To compensate a Set of Filters by Means of an Experimental
Determination of the Densities produced*

Before proceeding to this example it will be necessary to introduce a further definition.

It is found that over the region of correct exposures the difference of densities obtained is proportional to the difference of the logarithms of the exposures. This ratio is known as gamma, so that we have

$$\gamma = \frac{D_1 - D_2}{\log. E_1 - \log. E_2} \text{ or } \log. E_1 - \log. E_2 = \frac{D_1 - D_2}{\gamma}$$

Now to reduce an exposure of E_1 to E_2 we must clearly add a filter the transparency of which is $\frac{E_2}{E_1}$. Its opacity must therefore be $\frac{E_1}{E_2}$ and its density $\log. E_1 - \log. E_2$. But this has been shown to be equal to $\frac{D_1 - D_2}{\gamma}$.

Hence this last expression gives the density of the required compensating filter.

The corresponding transparency is

$$\frac{1}{\text{Antilog. } \frac{D_1 - D_2}{\gamma}}$$

and if we wish to correct by a reduction of area, the area would obviously have to be reduced by this factor.

For example, supposing that with a certain emulsion and illuminant and developing to a value of gamma=0.65 we obtained the following densities:

Filter.					Density.
Red	..	..	..	..	1.33
Green	..	..	..	..	1.11
Blue	..	..	..	..	1.03

As the blue gives the lowest density we must clearly correct for the red and the green.

For red,

$$\frac{D_1 - D_2}{\gamma} = \frac{1.33 - 1.03}{0.65} = \frac{0.3}{0.65} = 0.46.$$

Similarly, for green,

$$1.11 - 1.03 = 0.08 \text{ and } \frac{0.08}{0.65} = 0.123.$$

Hence the required added densities are 0.46 and 0.123 respectively.

Also the antilogs. of these are 2.88 and 1.33, and the reciprocals of these are 0.3472 and 0.752 respectively.

These are the factors for the reduction of areas which would therefore have to be brought down to 34.7 and 75.2 per cent. of the originals if this method of compensation were adopted.

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4. THE PHOTOCHEMICAL RECORD. THE RECORDING PLANE (TRICHROMATIC RECORD)

The photographic record constituting the original or master film for a motion picture in colour may take one of the following forms:—

1. *Successive Frame.*

Separation negatives of normal dimensions successively recorded on a single film strip coated with a panchromatic emulsion. Camera normal.

2. "Three-Strip."

Namely, three films for exposure in a beam-splitter camera embodying two exposure apertures. Two of the films constitute a

bipack which is used in one of the apertures or gates, and the remaining film is exposed in the other gate.

Example: Eastman Three-strip film as supplied for Technicolor and Dufaychrome.

3. *Integral Tripack* (Monopack, Multilayer). Camera normal.

(a) Standard 35 mm. A. Layers containing non-diffusing colour couplers.
Original is a coloured positive by reversal processing.

Examples: Ansco Color, Agfacolor Reversal, Gevacolor Reversal.

B. Processed by controlled colour development.

Examples: Kodachrome, Ilford Colour.

(b) Original is a coloured negative. *Examples:* Agfacolor Negative, Without integral mask. Layers containing non-diffusing colour couplers.

(c) With integral masking. *Examples:* Eastman Color Negative, Ansco Color Negative.

4. *As alternative 3 above, but sub-standard.*

Many Technicolor films have been "blown-up" from 16 mm. Kodachrome originals. The method is equally applicable to Ansco Color or Agfacolor 16 mm. reversal positives. Camera is sub-standard.

5. *Additive Screen or Mosaic Negative.*

Camera normal.

Example: Dufaycolor Negative.

6. *Stripping Tripack.*

Without colour development. *Examples:* Technicolor, Du Pont Camera normal. (3-colour bipack), Gevaert,

Coote, and Kodak patents.

Such a material would resemble Kodachrome, but the layers would have to be separable, yielding normal separation negatives.

7. *Single Frame Multiple Image.*

Separation negatives of sub-standard dimensions simultaneously recorded within the area of a normal sound frame (16.03 × 22.05 mm.). Normal motion picture panchromatic film is employed. Beam-splitter camera required, such as the cameras of Thomascolor, Roux, Francita, Cinecolor (British).

8. *Bipack* (Two-colour).

Exposed in a normal camera equipped with special gate and magazine. Camera modified.

9. *Lenticular Film*. (In effect, an additive screen process.)

Exposed in a normal camera.

1. **Successive Frame Method**

Title, cartoon, or animated puppet films are generally made by successively exposing a set, or frame, of three exposures made respectively through red, green and blue tricolour filters, use being made of a normal high-grade camera equipped with register pin movement. It is certain that only first-class apparatus is good enough, since microscopic inaccuracies of film positioning between successive exposures will result in colour fringes in the final print. It is also essential that the single frame camera-turning mechanism, by which the successive exposures are made, should be extremely accurate so that there are no variations in the exposure time given for each single frame.

Detailed instructions will be found in the Technicolor and Dufaychrome sections (see pages 414, 451). Reference will only be made here to essentials.

- A. The order of exposure should be through the colour filters Blue, Red, Green. (Required by Technicolor.)
- B. Wratten filters A, B and C should be used, namely, Nos. 25 (Red), 58 (Green) and 47 (Blue). Generally used as unmounted gelatine. Optical flats can be used, but it is difficult to ensure perfectly parallel mounting for the three. Filters made by Dufay-Chromex used for Dufaychrome are Chromex 523 (Red), 524 (Green) and 525 (Blue).
- C. Negative film stocks recommended are Eastman Background X or Plus X. Filter factors for the former for Wratten filters 25, 58, 47 are respectively 4—6—10. The speed of Background X to tungsten lighting is approximately Weston 16.
- D. Definition of the negative should not fall below a resolving power of 50 lines to the millimetre.
- E. Picture Aperture as per B.S. 677, 1942, viz., 22×16 mm.

2. **"Three-Strip" Film and Emulsion Combinations for use in Beam-Splitter Cameras**

When the Technicolor organization first began to use their three-colour cameras, the combination of films they employed, comprised a bipack which was intended primarily for two-colour photography and which recorded blue on its front element, red on the rear film, and a separate high-speed (Super XX) panchromatic film to record green.

The front film of the two-colour bipack carried an orange-red filter layer over its emulsion, and this, together with a magenta (minus-green)

filter placed in front of both films, ensured that only blue light was recorded on the front film and red on the rear element. A tri-colour green filter was used ahead of the panchromatic film.

A minus-green filter, such as Wratten 32, was necessary because both front and rear elements of a two-colour bipack have some green sensitivity. The type of magenta filter required has a daylight factor of approximately 5, while the tricolour green filter has a factor of 6 under the same conditions.

These losses due to filter inefficiencies were largely eliminated when Technicolor was able to employ three films which had been made by Eastman Kodak specially for the beam-splitter camera. The new combination of films (first used about 1940) comprises a bipack with a purely blue-sensitive front film together with a blue and red sensitive back film—a suitable red filter being carried by the emulsion of the front element. This type of bipack requires no external filter as neither element has green sensitivity. For the separate green record a highly green sensitive emulsion is used together with a minus-blue (yellow) filter to account for the inevitable blue sensitivity. The yellow filter required will probably have a factor of approximately $2\frac{1}{2}$ —representing a considerable saving on any tricolour green filter.

It is likely that the original two-colour bipack and single panchromatic film had an effective speed of Weston 3, while the new set of three films has a speed of approximately Weston 6.

3. Integral Tripack

Integral Tripack, or Monopack, as it is called in America, has not quite come up to the expectations of those who thought it would eliminate the inconveniences of the beam-splitter camera. The problem of making perfect three-colour separation negatives from a positive, or a negative, colour transparency immediately presents itself, and we know that this necessitates masking. If the masks are separate films registration is almost impossible to apply as a standard laboratory technique. In general, as is now well recognized, magentas have excessive absorption of blue and, to a lesser degree, of green, while cyans also have excessive absorption of blue and green. One of the alternatives is to make a low density positive from one record and to superimpose this upon the second record. In some multilayer materials a separate layer may be included which is converted to the desired hue for a colour mask. Kodak patents cover an elegant solution of the problem. In the Ektacolor¹ negative the cyan coupler is orange in hue instead of colourless as in, say, Agfacolor, its absorption being designed to be just sufficient to cancel the excessive blue and green absorptions of the cyan. When completed its orange colour is simultaneously destroyed, thus providing a negative cyan image combined with an orange positive, the latter cancelling the density to blue and green light. Such

¹ This material will probably be known as "Eastman Color Negative."

a masked cyan image will have normal contrast to red light and zero contrast to blue and green light. Similarly the magenta is yellow in hue sufficient to equal the absorption of blue by the magenta. The combined magenta negative and yellow positive works as the cyan negative and orange positive just described—it will have correct contrast to green light and no contrast to blue light. From such a master masked negative, separations showing marked improvement can be made.

An ingenious alternative solution of the problem in the case of a multilayer negative material is described in B.P. 602,881 of the General Aniline and Film Corporation, makers of Ansco Color Film. The layer carrying cyan coupler contains a uniformly distributed non-diffusing yellow or red azo dye of low density, and the magenta layer a yellow azo dye of low density. After development and fixation by the usual technique, the azo dyes are bleached by acid thiourea as in the Gaspar process. This bleach has no irreversible effect upon the dyes produced by the colour development. The yellow azo dyestuff in the magenta layer and the red azo dyestuffs in the cyan layer are destroyed *in situ* with the negative silver in the two layers. Any reduction of the cyan and magenta can be restored by a short rinse in a dilute solution of sodium carbonate. The contrast of the masking images so produced is controlled by the bleaching time of the acid thiourea. Subsequently, the silver is removed by the usual ferricyanide bleach and fixation. Alternatively the azo dyes may be added by use of a dye precipitating solution such as diphenylguanidine acetate and after drying controlled diffusion effected by washing in water containing isopropyl alcohol, which removes the precipitating agent from the top layer only. After precipitation of the yellow dye in the magenta and cyan layers by immersion in a solution of a yellow azo dye, the yellow is washed out of the top layer. The remaining steps are identical to those described above.¹

Such masked negative integral tripacks have not been used so far in any major production. It may well be, however, that such materials will yield results superior to those so far obtained with monopack as an original record for processes such as Technicolor. A panchromatic matrix material would enable positive master printers to be made direct from the colour negative. Otherwise the making of separation negatives would involve an intermediate positive stage, the separation yielding a set of positives. The weaknesses of the Gaspar processing technique would soon reveal themselves in achieving colour masking by such a method on a commercial scale.

If the monopack original record is a reversal positive, better separations will be made if it has been slightly underexposed in order to give good highlight detail. The total density range of Kodachrome, for example, is approximately 2.6, the total range being 0.13 to 2.75. Where the density range is 2.4 or less the exposure of the separation

¹ See also U.S. 2,431,996, Dec. 2, 1947.

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negative should yield a density of 0.3 for the deepest shadow on the transparency in which detail is to be recorded. Suitable negative materials are Ansco One-Strip Color-Separation Film Type 155,¹ or Kodak Super XX. Recommended Kodak filters for separation from Kodachrome are Wratten 29 (Red), 61 (Green), 49 (Blue). The filter factors and relative exposure required will be:—

Filter.	Relative Exposure.	Filter Factors.
Wratten 29	1.0	5.3
" 61	1.5	8.0
" 49	4.0	21.0
Plus 2A		

Separations can be made by contact or by optical projection. The negatives should be developed to a gamma of approximately 0.75. It is

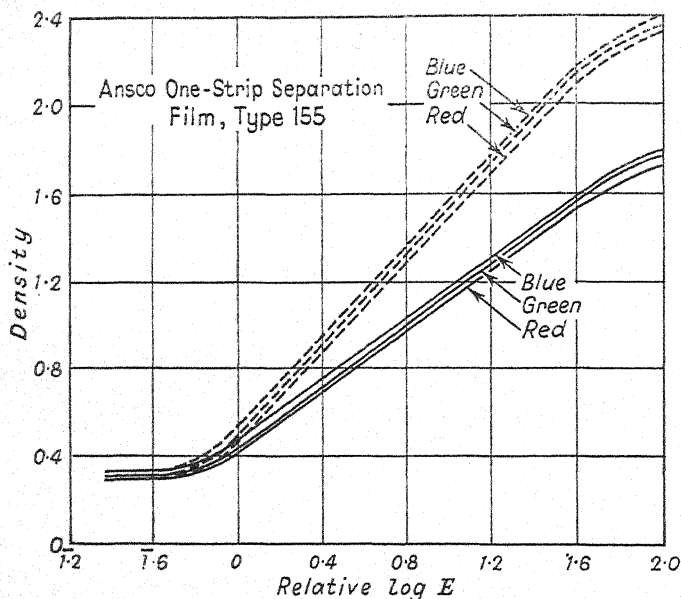


FIG. 60.—Characteristic curves for Ansco Film, Type 155.

Courtesy of Ansco; H. C. Harsh, J. S. Friedman and Journ. Soc. Mot. Pic. Eng.)

presumed that a reference grey scale chart has been included in the original and the maximum density of the white step should be rendered in the separation negative of density not exceeding 1.5. All steps of the chart must be rendered as nearly identical densities in the three separation negatives. The highlights must not be so "burnt up" as to have lost detail. When making separations by an optical printer, condenser illumination is usually employed, and diffusion is not essential, provided a point source, such as a Siemen's "Solid Source"

¹ See also page 396.

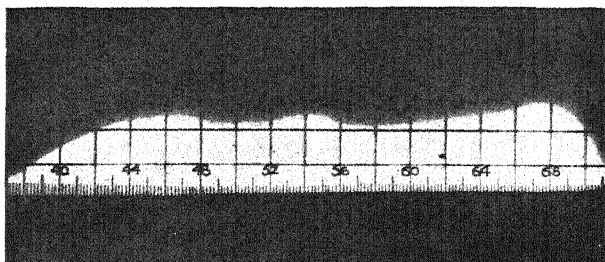
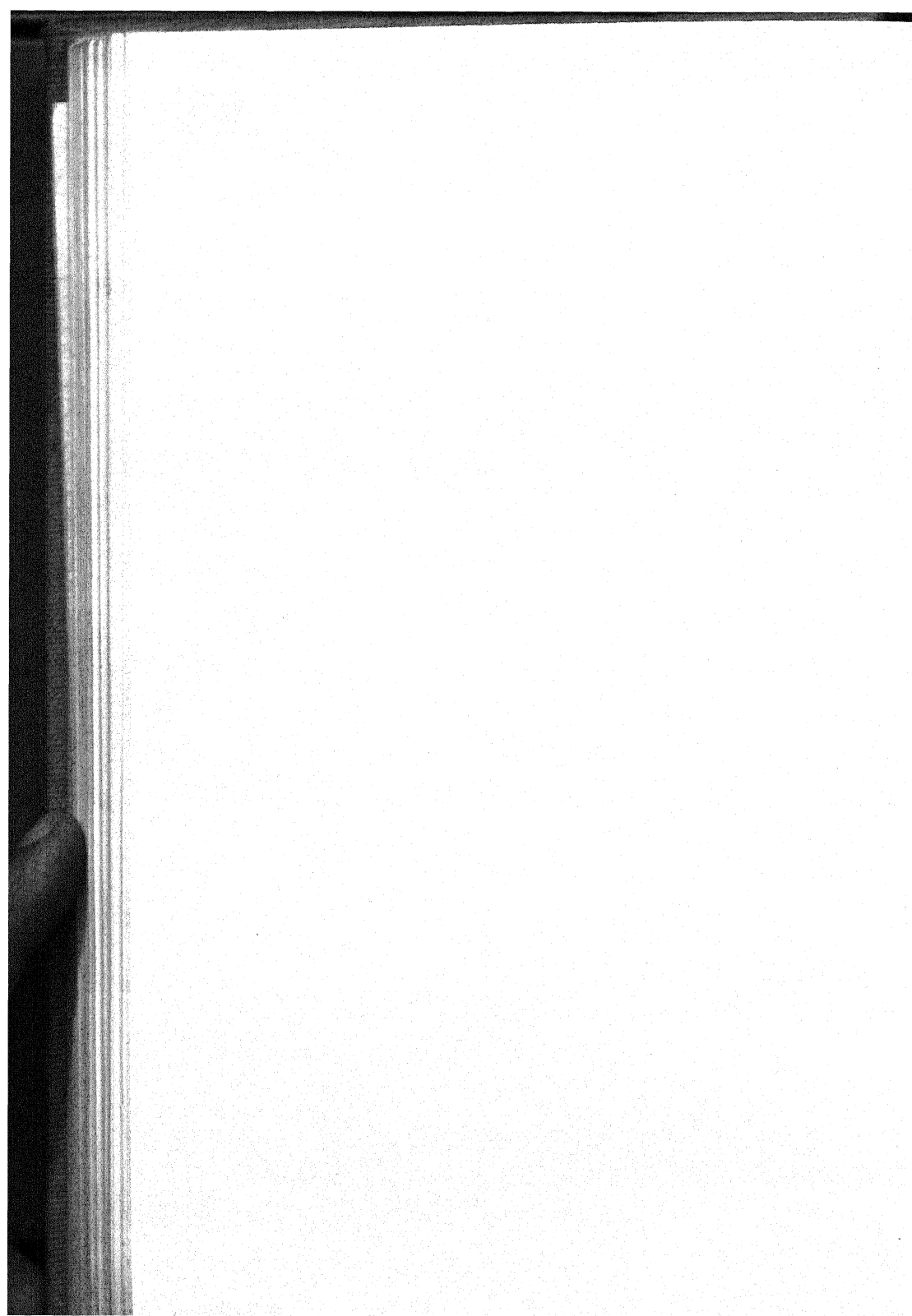


FIG. 61.—Ansco One-Strip Separation Film.
Wedge spectrogram showing spectral sensitivity.



tungsten filament lamp is employed. The only advantage in diffusion is to obtain perfectly even illumination.

When using Ansco Type 155 "One-Strip Color-Separation Film" it is the intention of the manufacturer that the separations should be made as successive frames on the one 35 mm. strip to ensure that during processing the shrinkage or other changes in the physical properties of the film will remain identical for all three separations. In this product equal contrast is obtained for the red, green and blue filter exposures. The gamma recommended for separation from Ansco Type 735 originals is 0.65. If the original is masked the gamma would have to be appreciably higher and the material has adequate gradation latitude to permit this without using parallelism of contrast against colour. The normal density range of a Type 735 original is approximately 1.6. It will be observed that this range is covered in the straight line portion of the characteristic curves (Fig. 60).

According to H. C. Harsh and J. S. Friedman,¹ "Another feature of this new film is the sensitization which is extended farther into the red than a normal panchromatic film. The reason for this is apparent by reference to Fig. 61. It will be noted that the cyan-dye image has a maximum absorption at 680 $m\mu$, which corresponds to the maximum of the red sensitivity of the film. This enables one to use an extremely sharp cutting filter such as Wratten 70, the cut-off of which is well beyond the sensitivity range of a normal panchromatic film." This gives a red filter separation which is nearly ideal, increasing the saturation of reds and of those colours rich in red.

The tricolour one-strip analysis Type 155 film is used on an optical printer equipped with registration pins and the copy head must have a skip frame action. A filter wheel is synchronized to the action and a set of three frames made from each frame of the original. At the optical stage, fades, lap dissolves, or other special effects can be included. Development is carried out in a buffered borax formula of the type used for variable density sound films.

From the successive-frame separations a duplicate set of separate negatives can be made via intermediate positives by the usual technique, or a set of separate positives can be made which are used as masters for printing direct on to Type 732 Ansco Color Printing Film, use being made of a standard contact step printer equipped with registration pins. This method involves three separate printings with the appropriate filters.

C. G. Clarke² has given considerable information on the employment of "Eastman Monopack" (viz., special Kodachrome) in photographing the Twentieth Century-Fox Film production "Thunderhead,"

¹ Harsh, H. C. and Friedman, J. S., "New One-Strip Color-Separation Film in Motion Picture Production," *Jour. S.M.P.E.* (Jan. 1948), pp. 8-13.

² Clarke, C. G., "Practical Utilization of Monopack Film," *Jour. S.M.P.E.* (Nov. 1943), p. 327.

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which was released in Technicolor. The whole film was photographed in monopack including a wide range of background projection shots. He claims an equivalent increase of speed of 25% as compared with the beam-splitter. Warning is given as to a tendency to increase contrast and it is stated that slightly diffused daylight reproduces as bright sunlight, and light blue skies "become vivid blue." Cloud-filled skies are "most ideal." Shadows should be illuminated with the aid of reflectors and booster lights. M-R lamps, using Y.1 filters, are used for this purpose. Bunting diffusers are useful to soften overhead sunlight. An ultra-violet absorbing filter is used for all scenes, exterior and interior—Wratten 114A.

Apertures varied between $f/2.8$ and $f/16$. Interiors were photographed at $f/2.8$. Exterior exposures varied from $f/2.8$ for the dark canyon and waterfall scenes to an average of $f/8$ for the open landscapes. Exterior night scenes were taken in daytime, and for these scenes the film was one stop underexposed to increase density of shadows. Colour grading of the final Technicolor was forced in the bluish direction to simulate moonlight.

Rushes were made as a reversal black-and-white print from the original colour positive. "After a little experience in judging these reversal prints, the cameraman can gain quite a good conception of what quality the final colour print will be."

Interior sets must have very soft lighting to avoid excessive contrast in rendition of flesh modelling.

"Many scenes in 'Thunderhead' would not have been put on the screen had it not been for easily portable cameras. Not only is production time saved in placing cameras, but extreme camera angles can be employed and a greater selection of photographic lenses may be utilized. This is particularly so with the shorter focal length lenses, commonly called wide-angle lenses. Modern pictures utilize the advantages of wide-angle lenses for their greater depth of focus and interesting perspective."

4. Sub-standard Integral Tripack

See paragraph 3, page 132.

5. Additive Screen or Mosaic Negative

The full technique is discussed under "Dufaycolor." We will only remark here that this type of negative colour film has hitherto only been of value as comprising the means of printing Dufaycolor positive. The screen or réseau dimensions forbid its use as an original for subtractive analysis. Experiments were made in 1940, using Dufaycolor negative from which black-and-white *positive* separations were made for printing Gasparcolor (dye-bleach process). The resulting print exhibited marked granularity and unpleasant "boil." A réseau of some 150 lines to the millimetre would yield a master negative from which prints of accept-

able definition and tranquillity could be made, but the likelihood of such a screen being manufactured is very remote indeed.

6. Stripping Tripack and Bipack

In B.P. 565,838 and 565,836 of Technicolor, there is described the machinery for successively stripping layers from a multilayer film to a new film base, "wherein the outer face of the layer and its old base is weakened, or a preliminary weakening is completed, while the two bases are travelling in superimposition on a carrier" (pin belt)—"and the new base, carrying the transferred layer, is peeled apart from the old base, either while still on the carrier or after the composite film has been removed from the carrier. More than one layer of a multilayer film may be so stripped—either by re-threading the films into the same apparatus or by making provision for successive stripping operations at different points." Multilayer materials may have the same substratum between successive layers, being softened before stripping by controlled penetration of the same solvent: or they may have successive substrata soluble in different solvents, *e.g.*, water and alcohol. The belt may have markings so that when the layers are being transferred corresponding sprocket holes of the different films may be caused to engage the same teeth of the pin belt in order that slight irregularities in the pitch of the band may not impair subsequent registration.

B.P. 574,139 and 574,137 of Kodak describe a stripping tripack of a type obviously suitable for handling by the machinery just described, and B.P. 574,138 deals with alternative mechanical devices of a similar nature to the Technicolor patent.¹ The Kodak patent states that "the multilayer stripping film which can most suitably be employed in such a process comprises, in its simplest form, a support having on one side at least two superposed silver halide emulsion layers separated by a layer of colloidal material soluble in an aqueous medium, or at least so softenable by an aqueous medium that it will strip readily from one of the emulsion layers. Preferably it comprises a support having on one side three superposed silver halide emulsion layers, the two outer emulsion layers separated by a layer of colloidal material, soluble or at least permeable in an aqueous medium, the inner two emulsion layers separated by a layer of water-insoluble colloidal material soluble in aqueous organic solvent media or alkaline solution. The separating layers preferably consist of cellulose esters and may be so composed that they are both water-soluble. The principle employed is to interleave the bottom red sensitive emulsion and the middle green sensitive member of the tripack with a thin layer of cellulose acetate of say 19% acetyl soluble in water and alcohol. The coating may contain 1% of the cellulose acetate in a mixture of 30 parts of ethyl alcohol, 30 parts of ethylene glycol mono-methyl ether and 39 parts water. This is softened

¹ See also B.P. 574,164, 582,438 and 629,032.

in the stripping sequence by a dilute alcohol solution. Next the interleaving layer between the ortho middle layer and the blue-sensitive top layer is a water-soluble cellulose acetate of acetyl content 17% from a 1% solution of cellulose acetate in water. To strip the top emulsion treatment with water is sufficient to bring about separation. Such a stripping tripack is used to provide separation negatives by stripping the upper two layers mechanically and in accurate registration to two new film supports, the bottom layer being allowed to remain on its original support. Development is carried out after stripping has been completed. (Also B.P. 582,439 and 582,436.)

See also Du Pont B.P. 537,232.

Du Pont in B.P. 505,861 describe a bipack from which three separation negatives can be obtained by a sequence of operations applied to the rear element. The bipack consists of a front blue-sensitive yellow-dyed element single-coated of the normal type. The rear element carries a two-layer coating, the front layer being green sensitive and the back layer red sensitive. Between the two layers is a red filter layer. The yellow dye in the front emulsion and the red filter interleaving layer are destroyed in the developer.

After development of the rear element a positive intermediate print is made from the combined green and red negative records. Next, the double-layer negative is bleached and the top layer only is re-developed with a viscous developer. On fixation the bottom layer is eliminated. The intermediate positive made previously from the two-layer film is now used as a mask and a print made from the two combined. The resulting print will be a duplicate negative of the destroyed image which constituted the rear emulsion. We therefore now have three negatives. The front element of the bipack, the front negative of the double-coated rear element and a third negative derived in the manner described.

The claims are:—1. The method described for the production of independent colour separation photographic records from two or more colour separation records inseparably superposed on the same support, characterized in that the elimination of one of the records is effected after the records have been developed to silver images, by bleaching all the records to convert them to silver salts, re-developing all but the innermost record by means of controlled development and finally dissolving away the undeveloped silver salts which formed the innermost record.

2. The method according to claim 1 applied to the processing of the multilayer element (or elements) of a bipack in which one support (or both) carries two superposed emulsion layers each sensitized to a particular colour range and in which the layers of both members of the bipack have been exposed simultaneously to form the original colour separation records.¹

¹ See also B.P. 623,644, May 20, 1949. Stripping Bipack. Du Pont patent.

Contemporary technical procedure in the employment of bipack is well described in a recent paper presented by John Boyle, A.S.C., at a convention of the S.M.P.E. in October 1946, to which we are indebted for most of the information here given.

The following changes are necessary to convert the N.C. type Mitchell for bipack:

- (1) Move lenses towards the film (emulsion) plane a distance of 0.0045 in., then use normal calibrations for focus. Cameras with standard instead of "slip-ring" lens mounts would have to be either eye focused or recalibrated.
- (2) Adjusting lenses will necessitate "skimming" the ground glass back 0.0045 in.
- (3) Remove "stripper" shoe at back of main sprocket and replace with "cutaway" shoe.
- (4) Lock off clutch.
- (5) Substitute either a four-roller pressure plate, or a solid pressure plate. In the four-roller plate the top roller is straight while the other three rollers are crowned 0.003 in. The four-roller pressure plate is patented by the Cinecolor Corporation and license for use is granted by the patentees. The solid type plate is crowned 0.003 in. and is of polished chrome.¹ Pressure can be obtained with a solid screw or by use of a spring having twice the tension of the normal spring. In practice use is generally made of the solid screw for the four-roller plate, being careful to avoid "run-outs."

Mr. Boyle states that the proper adjustment of the pressure plate is very important; insufficient clearance with consequent "punching" will cause perforation damage and out-of-register images, while too much clearance will destroy contact of the rear negative, resulting in "breathing" and out-of-focus pictures.

A test chart is photographed at the end of each day's work and the paired negatives carefully examined for contact, any lack of which is ruinous to the rear image. The back negative should be compared with a standard of excellence retained as a control.

Coated lenses have given the best results and satisfactory pictures have been made with lenses varying in foci from 24-40 mm., but such wide-angle lenses must be used with discretion.

Owing to the difficulty of obtaining adequate illumination with tungsten lighting and variations in colour temperature, only the exterior type of bipack has been used in the Hal Roach Studios, in which a large number of two-colour films have been made. Generally H.I. arcs are employed, the general illumination being identical to Technicolor.

Boyle notes that back light should be kept to a minimum, only the

¹ The solid type pyramidally crowned is used by Republic Pictures Corp. for their Trucolor bipack Mitchell cameras.

necessary amount being used to give detail in hair and separate the colour planes. An undue amount gives bluish highlights. In exteriors, back light causes grass and foliage to reproduce as brownish in hue and should be avoided. For street scenes and exteriors where there are no deep shadows, overcast weather conditions have given the best results (H.I. arcs and booster lights assisting) for foregrounds and faces. The use of an ultra-violet absorbing filter helps in rendition of flesh colours and textures. In general, the set should be fully lighted, avoiding deep shadows. With coated lenses at an aperture of $f/2.8$ a keylight of 500 foot candles is employed, filled to an over-all luminance of 650 foot candles. For night effects and somewhat deeper shadows, less fill and more cross-light should be used. Night effects are accentuated by the use of "practicals" and brightly lit windows. Generally some 20% of the lights used are tungsten lamps used with Macbeth "Whiterlite" filters. Occasionally ordinary incandescent spots are used without correction to emphasize reds or orange. Because of the volume of light necessary, large units are used as far away from subjects as set construction will permit. The familiar Y-1 filter is used on all H.I. spots, to cut the excessive blue-violet, but as in Technicolor lighting, the Mole-Richardson broadsides are used without filters. The side arcs give a colour-temperature of 5,500° K. The H.I. arcs with 170-Y-1 Brigham gelatines are 5,900° K.

Make-up should be on the light side to avoid a red-orange or sallow complexion. Lip rouge should be an orange-red. Grease has given better results than "pancake" and no make-up is used above No. 25. Owing to the light make-up, blended modelling is used to prevent masking appearance and to break up colour into planes. For men, a beard cover must be used, otherwise the beard will reproduce as a blue shadow. No make-up is used on children. Three-colour make-up has not been a success, indeed standard black-and-white make-up in lighter values has been found more suitable.

White shirts, towels and bedding should be dyed a buff, otherwise the whites will be too "cold."

Fluorescent cloth has been successfully employed to obtain a colour of high saturation.

Very complete preliminary tests should be made to determine the precise reproduction (in advance) of all the principal costumes and furniture and interior decoration.

7. Single Frame Multiple Image

It does not appear that the technicians responsible for the development of three-colour subtractive processes such as Technicolor, Cinecolor (in its three-colour form), Dufaychrome, have been impressed with the possibilities of optical systems capable of providing two, three or more separation negatives within the area of a single frame. Before the

demise of Gasparcolor in England owing to the outbreak of war in 1939, the writer had proved that this method should by no means be despised. If designers of beam-splitting prism-lens units for additive processes had stopped at the camera stage they would often have made a useful contribution. Generally, further refinement of the taking system never occurs because the inevitable insolvency which overtakes these optimists puts a stop to further work. With fine grain negatives it should be possible to make dupe 35 mm. optical blow-ups of adequate quality. Needless to say, the negatives must be absolutely free from parallax, and positioning of axes must be constant. The method warrants further investigation. It would be of great interest to examine the result of "blowing-up" Thomascolor, or Roux miniature negatives.

8. Bipack

Bipack is still popular as a convenient way of recording. Its survival has been due firstly to the inconveniences of a 35 mm. beam-splitter, secondly to its low production cost and to the low cost of two-colour prints. Toning of double-coated positive (coated on both sides of the film base) remains the cheapest of colour printing techniques. In America the predominance of Technicolor was bound to arouse competition, and so we saw the resurrection of Multicolor, in the form of Cinecolor, of Magnacolor,¹ and of other ancient and respectable processing procedures. In due course Technicolor replied with "Technichrome," three-colour dye transfer from three matrices derived from the *two* bipack negatives. Other newcomers are Fullcolor and Trucolor.

As has been stated in the "Historical Summary," the bipack was suggested by the progenitor of all colour processes, Ducos du Hauron, in F.P. 250,862, 1895, and by A. Gurtner, B.P. 7,924, 1903—the latter patenting the idea of combining two plates emulsions face to face, the plate nearer the objective to be coated with a slow silver chloride, or chlorobromide, emulsion unsensitized, and the emulsion surface coated with a red-orange filter, the rear plate being coated with a red-orange sensitive emulsion. Other bipacks followed. G. Battistini patented the arrangement of bipack and single film in two gates at right angles to give three-colour negatives, B.P. 873, 1915. W. Buchanan-Taylor and others patented a similar arrangement in B.P. 12,469, 1914. This camera embodied a semi-transparent mirror to reflect the light to gate B, accommodating a bipack. A. Hamburger and W. E. L. Day in B.P. 136,595, 1918, patented the same "semi-dialyte" type of camera.

The bipack had the green sensitive element in the back and the front unsensitized emulsion presumably was surface-coated with a minus-blue filter. In the second gate a panchromatic emulsion was used in conjunction with a red filter. Hamburger never used this arrangement because he never perfected a three-colour process.

¹ Still worked today at the Hollywood laboratories of Consolidated Film Industries, but being rapidly supplanted by Trucolor, produced by the same firm.

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P. D. Brewster was one of the earliest workers to use a bipack for two-colour recording, B.P. 2,465, 1915, and he was one of the first, if not the first, to use registering pins in cameras and projectors, U.S.P. 1,359,024, 1920.¹

For a number of years the Du Pont bipack, known as "Dupac," was the material generally favoured. It is not listed as a regular product of

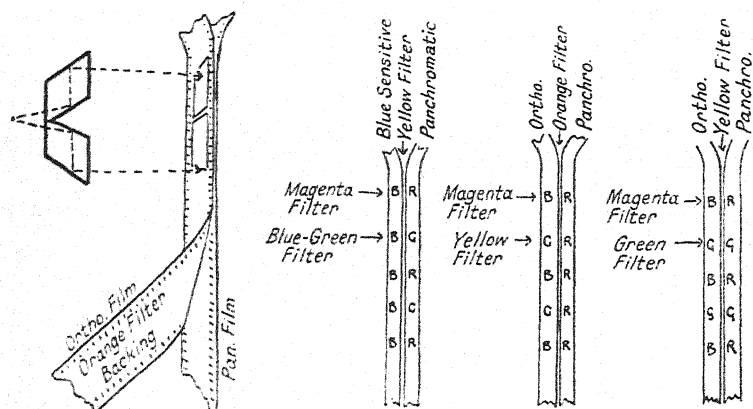


FIG. 62.—Three-colour negatives obtained with beam-splitter camera using bipack (Spencer).

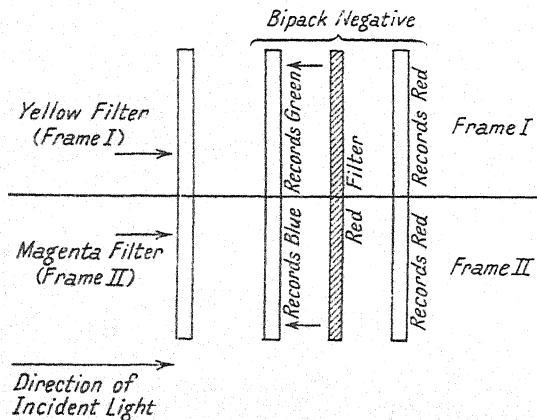


FIG. 63.

Du Pont any more, and the film generally used today is Eastman Type 1234, a red dye overcoated orthochromatic negative material of medium speed. Colour sensitivity and contrast is balanced to daylight. This is used as the front film in combination with Bipack Panchromatic Type 1235. Type 1236 is an alternative front element balanced for tungsten illumination at 3,200° K. to 3,400° K.

¹ See also W. V. D. Kelley, p. 135.

Modification of normal cameras to accommodate bipack has been studied by the leading camera manufacturers. In general this involves special magazine design, adequate pressure pads in the gate to ensure contact, and re-calibration of the normal focus.

Bipack can be made to yield three-colour separations provided a beam-splitter is used which gives two sub-standard images within the area of a single frame, as in the systems of Roux (French), Cinecolor (British), and others. L. W. Oliver, H. D. Murray and D. A. Spencer described in B.P. 363,000 such a method. The pairs of images are exposed through yellow and magenta filters. Other alternative combinations are described (Figs. 62, 63).

In B.P. 395,124 Agfa described a lenticular bipack from which three-colour separations could be made. The front film was a normal lenticular embossed base coated with an orthochromatic emulsion. The rear film is coated, as in standard bipack, with a panchromatic emulsion. The emulsion of the front film is coated with the usual red-orange filter. The front film is caused to record two colours by means of a banded filter in front of the camera lens. The band is divided into three sections, magenta in the middle, and yellow on either side. Thus red is transmitted by both filters. The front film will bear a record in parallel bands of green and blue light. The rear film bears a continuous image which is a record of red light only. The films are reversal developed, or developed as normal negatives if desired. To print from either the green or blue record separately it is necessary to use coloured light, using a banded filter in the same position as when the picture was exposed. The printing is generally done on a panchromatic material using a registration pin contact step-by-step printer. For illumination a small source must be used, the filament being at right angles to the filter bands, and therefore horizontal. By temporarily blocking out one or other band of the filter one record at a time can be separated. The dimensions recommended for the filter bands vary for different objectives. The following is an example, as for daylight:—

ASTRO F/1.8—50 mm. TYPE III

	<i>Yellow Filter.</i>	<i>Magenta Filter.</i>
Height of Band	10 mm.	35 mm.
Width of Band	7 mm.	7 mm.

For printing from negatives taken with the above lens:

Height of Bands	25 mm.
Width of Bands	12 mm.

Excellent separation can be obtained but the loss of resolving power is excessive.

In B.P. 449,591, the writer and T. S. Wilding patented a bipack which is well worth further trial. The object is to improve the definition

of two-colour prints by designing a bipack in which the front element is the cyan printer. The *front* element is sensitive to red and blue only, a well recognized type of sensitizing used today for the rear layer of integral tripacks. The rear element is a high-speed orthochromatic emulsion. Using a minus blue taking filter we obtain a record of red-orange on the front negative and a record of green on the rear negative. The cyan printer being the front negative this image will have maximum sharpness, and the improvement in the final print is markedly superior to that yielded by the classical bipack with cyan printer at the rear. Obviously this bipack can be used in a beam-splitter, giving two images and using, say, magenta and yellow filters, we shall get four printers from one pair of negatives, the cyan printer from the front negative and the magenta printer from the rear; and from the other pair, a yellow

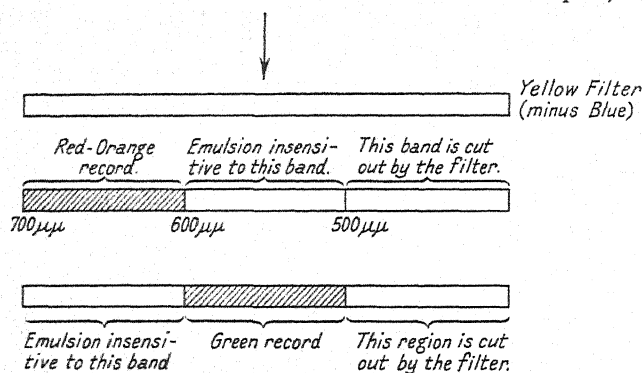


FIG. 64.—Bipack (Cornwell-Clyne).

printer from the front element and a second magenta printer from the rear element. The latter is an extra record which will not be used (Fig. 64).

9. Lenticular Film

In the 1939 edition of this book the author wrote, "Indeed, it is very likely that nothing serious will ever come of it." Ten years have passed and there is yet no cause to alter this opinion. The French are still enamoured of the idea, and optical printing systems appear in the patent literature now and then, but the flood has passed and there is only a trickle of effort left.¹ When this vein of ore was opened by the Frenchman, R. Berthon, in 1909, it looked like a new Klondike, but nothing is left now but a disused shaft or two and the debris of innumerable patent files. The history of this elegant notion is one of the minor tragedies of colour photography and marks one more failure of the optical designers in their contact with chemists for an ideal solution.

¹ Eastman have begun experimental work again, in Rochester, with the apparent intention of employing lenticular film for the projection positive only.

A full description will be found elsewhere of how lenticular film works. No material is today commercially available. The stereoscopic possibilities of cylindrically embossed film so often commended are little more exciting than those of colour photography.

The method failed owing to extreme difficulties of printing and to the presence of parallax fringing in the negative, especially when wide aperture lenses are used of focus longer than 50 mm. In projection, light loss is as great as in any other additive system. The projection lens and banded filter require high precision optics and mechanical mounting.

Unless there is some basic change in the nature of the photographic response of sensitive materials used at present in photography there is unlikely to be any further improvement as regards the limitations of the

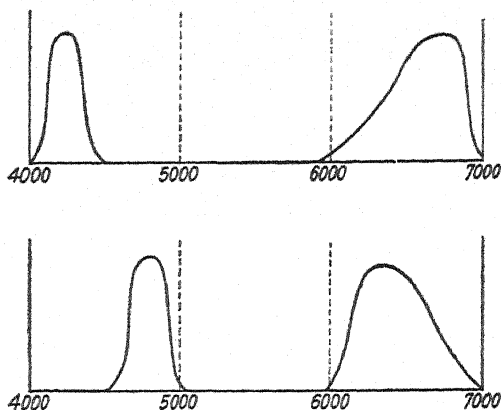


FIG. 65.—Photographically similar, spectrally different colours (Bull, Oliver, and Spencer).

colour recording in the three-colour process. These limitations have to be taken into account. This aspect of the three-colour process has been exhaustively treated in a paper by A. J. Bull, L. W. Oliver, and D. A. Spencer, from which the following extract is given [1]:

There are certain questions in subtractive colour photography which can only be answered by experiment with a process giving controllable and predictable results. Opinions on these questions appear from time to time, but these are usually based upon personal experience with processes largely subject to personal error.

Owing to the failure of the reciprocity law [2] it is impossible to translate light intensity into equivalent opacity for all densities in the negative, and, therefore, it is impossible to make use of colour filters whose transmissions agree with the colour mixture curves. Accordingly, for reasons which have been clearly stated [3] it is modern practice to divide the spectrum into five distinct regions by means of three slightly overlapping, sharp-cutting filters. This compromise, the only workable system so far evolved, imposes inherent limitations upon the truthfulness of colour rendering obtainable. Assume that the negative, positive, and printing surface

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all have straight-line characteristics (in other words, that every given monochrome tint in the original will be reproduced as the same tint in the reproduction), it can easily be shown that three-colour photography as at present practised is not capable of reproducing every colour exactly as it appears in the original. Consider, for example, the case of two colours represented by the transmission curves shown in Fig. 65 when photographed through normal tricolour filters. It is obvious that they will not appear visually identical, and yet, since they both have the same photographic energy distribution through the red and blue filters, the reproduced colour will be identical. Difficulties of this sort are usually dismissed by stating that colours with such transmissions are rare outside the laboratory. Our own experience in this respect has, perhaps, been unfortunate. We have occasionally met with fabrics whose colour is dependent upon narrow-banded, sharp-cut absorptions and reflections. The magenta colour found in such flowers as *cineraria* is a typical example.

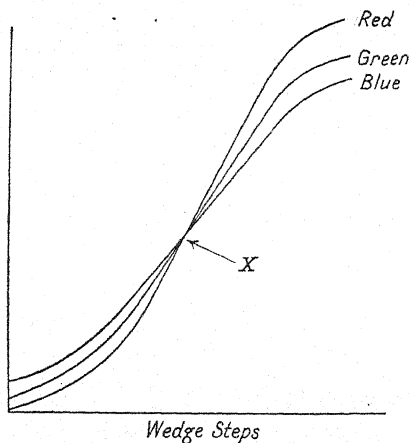


FIG. 66.

In an ideal set of separation negatives the varying intensities of the primary colours would be converted into equivalent opacities. Owing, however, to the failure of the reciprocity law, this equivalence is only possible over a *limited range of densities*. This fact, of little importance in monochrome pictorial photography, has a definite significance in colour work. Thus a magenta, for example, may consist of a considerable amount of red (recording, therefore, on the straight-line portion of the plate curve) and a small amount of blue (recording on the under-exposure portion), and the record is therefore not a strictly proportional one. Difficulties such as these are inherent in the characteristics of the photographic emulsion, but there are even more important factors, whose control is within the photographer's power. Unless the contrast of the three negatives is identical it will be quite impossible to maintain truthful colour rendering.

The diagram (Fig. 66) shows the curves of a tricolour separation set of a neutral wedge in which no attempt has been made to bring the contrast of the negatives into line by giving the blue filter negative *additional development*.

If a print is made by giving equal exposures through each of the three negatives, only at step X, where the curves cross, will a neutral grey be obtained, the darker steps being brown and the lighter ones purple. If the exposure is adjusted to make the heaviest density black, the purple colour of the lighter steps will be accentuated.

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- (2) JONES, L. A., and WEBB, J. H., *Reciprocity Law Failure in Photographic Exposures*, Communication No. 531, Kodak Research Laboratories.
- (3) BULL, A. J., and JOLLEY, A. C., *Proc. Opt. Soc.* (1904), p. 263.
NEWTON, A. J., and BULL, A. J., *Phot. Journ.* (1904), p. 263.
- (4) SPENCER, D. A., "Colour Photography in Practice" (Pitman, London, 1948), p. 303.

5. POSITIVE REPRODUCTION IN ADDITIVE OR SUBTRACTIVE PRIMARIES

(a) Additive Synthesis

Referring once again to analysis—knowing the spectral transmissions of a set of chosen synthesis primaries R. G. B. (for example, Wratten Additive Primary Filters Nos. 24, 59 and 47) by the use of the distribution curves (Figs. 55, 55A) of the standard observer (in the C.I.E. system of trichromatic colorimetry) it is possible to plot R. G. B. in terms of the co-ordinates $X Y Z$ of the C.I.E. chromaticity diagram (colour triangle) and measure the total range of colours which can be yielded by this particular set of R. G. B. primaries (Fig. 67). The choice of synthesis primaries R. G. B. is dictated by convenience. They must not be too dark and they must include the largest possible gamut of colour mixture.¹ It is to be noted that the original spectrum mixture data upon which the C.I.E. data is founded was determined by the use of three selected monochromatic spectral components. These are called *reference stimuli*. By linear transformation equations we can express this same data in terms of the distribution curves of any other set of reference stimuli, real or imaginary. Thus $X Y Z$ are imaginary stimuli calculated so as to yield more data than hue and saturation only. (See C.I.E. System.) We refer here to these facts to make it clear that many sets of R. G. B. are possible. It is highly desirable that the range between R. and G. should be as near as possible to the locus of the spectrum, otherwise the mixtures of these two would not yield saturated red, orange, yellow and yellow-green. On the other hand blue-greens are rarely met with in nature and it is less important that the range between G. and B. should lie close to the spectrum locus. It is clearly impossible, owing to the curvature of the locus, for any

¹ In mosaic processes the taking filters and the viewing or reproduction filters are the same, choice is therefore a matter of compromise. The best set would have transmissions lying between the best possible taking and viewing filters, if these were separate (Fig. 56A). In the Dufaycolor process the spectral transmissions of the réseau primaries are shown in Fig. 68 and the chromaticity range in Fig. 69.

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three points to be chosen which will contain all the spectrum colours, and the distribution curves of any real primaries must show negative values. Any colours lying outside the triangle R. G. B. obviously cannot be reproduced. (See, however, the possibilities of "masking.")

The analysis filters, as we have already learned in Section 3 (Trichromatic Analysis), must be such that the product of their spectral transmissions and the spectral sensitivity of an emulsion, or alternatively

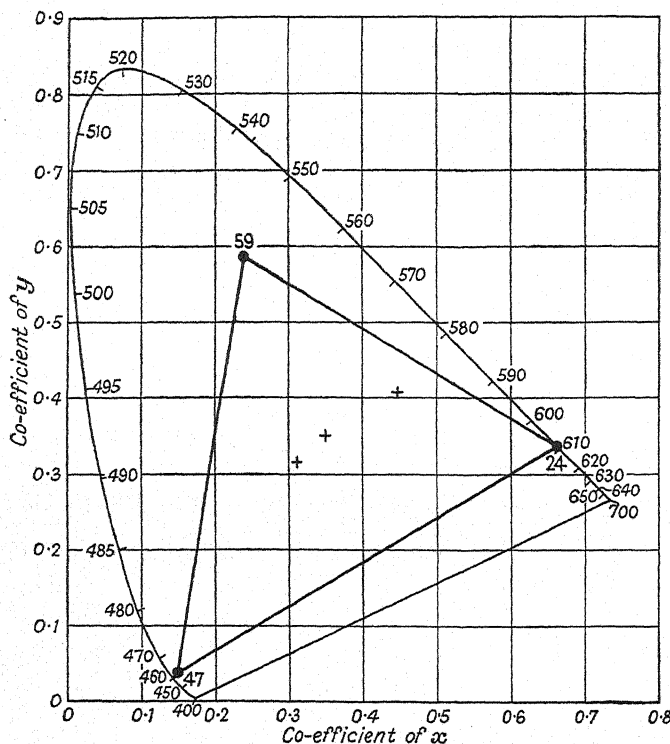


FIG. 67.—Synthesis primaries represented by Wratten filters 24, 59, 47, plotted on C.I.E. chromaticity chart.

the emulsion sensitivities alone in integral tripack separations (known as effective spectral sensitivity) is such that the resulting curves would have been obtained from actual colour matching experiments using the R. G. B. synthesis primaries for matching stimuli (Figs. 56-58). When R. G. B. of the synthesis have been chosen, the sensitivity requirements of the rest of the process can be calculated by the methods of standard colorimetry.¹ (C.I.E. System) (1) (2).

¹ See p. 112.

THE THEORETICAL BASIS

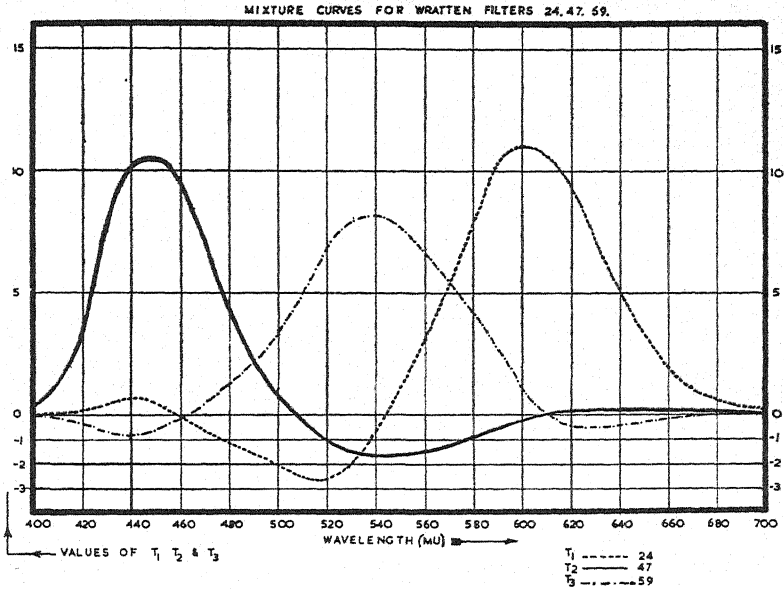


FIG. 67A.—Mixture curves of Wratten filters 24, 59, 47. (Courtesy of Dufay-Chromex Ltd.)

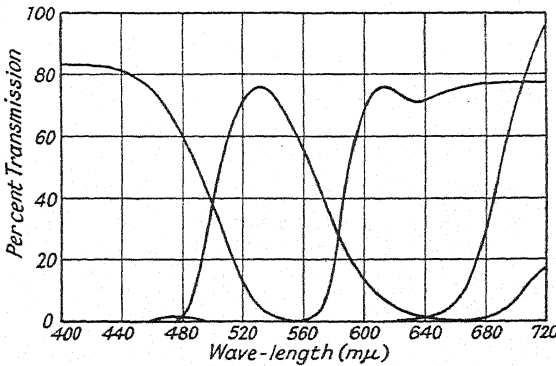


FIG. 68.—Typical spectral transmission curves for Dufay Réseau flat colours.

The writer must be excused for calling attention to the fact that his treatment of the analysis problem in the 1939 edition of this work anticipated the subsequent mathematical presentation in the hands of MacAdam, Hardy and others. The passage will be quoted because it was one of the earliest statements of the true nature of trichromatic photography:—

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“ The spectrum can thus be divided into three slightly overlapping and graduated, or ‘ vignetted ’ wavelength groups, the integrated stimuli of which will give three sensations closely approximating the sensations stimulated by chosen monochromatic wavelengths of red, green and blue. Thus the colour sensations which can be obtained with different proportions of these three will be contained in the

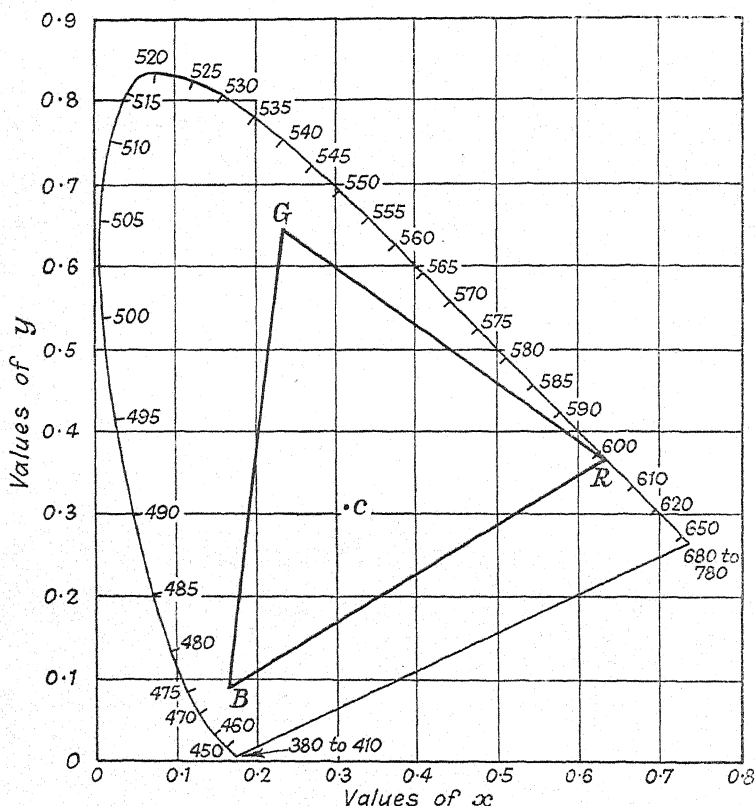


FIG. 69.—Dufay Réseau Primaries plotted on the Chromaticity Diagram.

triangle bounded by the position of the particular primaries chosen. The choice of primaries should be made for the same considerations which guide the choice in the case of a trichromatic colorimeter. Namely, it is desirable to reduce as much as possible the region of the colour field which lies outside the working triangle (see Guild 10). Guild's primaries were provided by Wratten filters (3):

With C.I.E. Illuminant A.					Excitation Purity %
71A	..	..	..	matching wavelength 636 M μ	100.0
62	..	..	..	„ „ 534 M μ	94.4
49B	..	..	..	„ „ 461 M μ	99.7
150					

" The position of Guild's and Bull's primaries (4) is shown on the colour triangle, Fig. 70. There is very little difference. (Bull chose 640 Mu, 537 Mu and 464 Mu.)

" Each of the three photographic records of the three chosen wavelength groups will record an integrated density representing the measure of the degree to which the original light can stimulate colour sensation corresponding strictly to that which is stimulated by the wavelength group transmitted by that filter. We have seen that these filter sensations nearly match the sensation received from monochromatic light. Consequently such filters are satisfactory analysers of primary stimulus value in any light, in spite of their

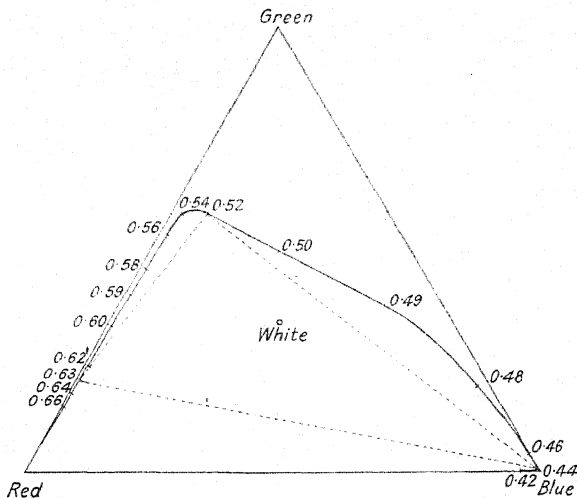


FIG. 70.—Full line interior triangle represents Bull's primaries. Dotted line represents Guild's primaries.

non-monochromatic transmissions. This statement is a fundamental definition of the theoretical basis of three-colour photography.

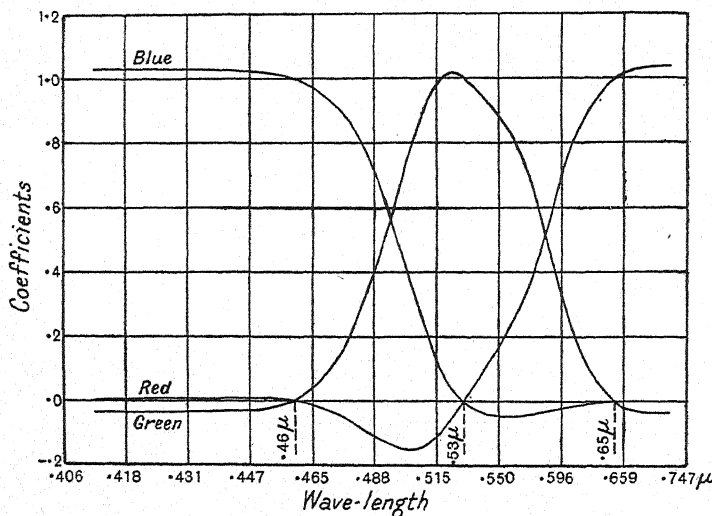
" If now we transform these densities into transparencies and illuminate them with light filtered into wavelength groups capable of stimulating identical sensations to monochromatic light of wavelength, say, 630 Mu, 537 Mu, 450 Mu, we reconstitute the original sensation, depending upon the three densities recorded in a given instance.

" Considered thus the three-colour process is a species of analytical trichromatic colorimeter using photographic registration of trichromatic values as densities, transforming these into transparencies and reconstituting the original colour by addition of primary coloured lights the values of which are modified by the variable densities in the

transparency. This is the 'additive' synthesis. Equally well we may use primaries of minus value to reconstitute the original. This is the 'subtractive' process."

If not rigorously sound, this was singularly near to being an accurate presentation of the problem.

But to continue—if for additive synthesis primaries we had at our disposal three monochromatic radiations of wavelengths 650 μ , 530 μ and 460 μ respectively, then the spectral sensitivities of three photographic emulsions whose recorded densities were to control the proportions of the above stimuli such as to comprise all chromaticities,



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FIG. 71.—Mean coefficient curves from result of 10 observers (W. D. Wright).

would have to be identical to the distribution curves of the reference stimuli R. G. B. of Wright's original trichromatic mixture data (Fig. 71).

For correct reproduction therefore the effective spectral sensitivities of the emulsions or filter-emulsions should match the distribution curves of the chosen synthesis primaries and the three processes must each have a "straight line" response with a gamma of unity. Since the distribution curves of any real primaries have negative portions and emulsions have not been made with negative responses, masking to cancel these has to be resorted to. The methods will later be dealt with. According to Wright, typical errors which may arise are these:—

(1) "Errors caused by neglecting the negative parts of the sensitivity curves, using instead all-positive curves that are linear transformations

from the C.I.E. system, but are as similar as possible to the positive portions of the ideal sensitivity curves. For true reproduction with emulsions having all-positive spectral sensitivity curves, reproduction primaries lying outside the spectrum locus would be required; instead,

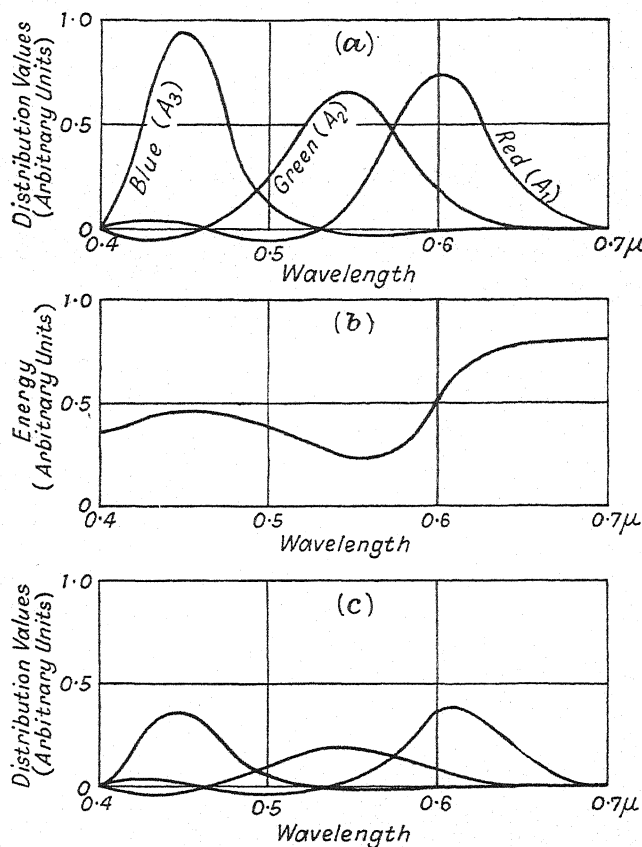


FIG. 72.—(a) Distribution curves for the equal-energy spectrum in terms of A_1 , A_2 and A_3 as primaries. (b) Energy distribution curve of light radiated by object being photographed. (c) Distribution curves for energy distribution shown in curve (b) obtained by multiplying (a) and (b) together (W. D. Wright).

A_1 , A_2 and A_3 , say, are used (Fig. 72). The primary most in error would be the green, A_3 , and colours containing any green would suffer a change in hue. All colours would be too desaturated, and the general trend would be as illustrated qualitatively by Fig. 73.

(2) "Errors caused by neglecting the negative parts of the sensitivity curves, using instead curves that follow as closely as possible the positive portions of the ideal sensitivity curves, without being linear trans-

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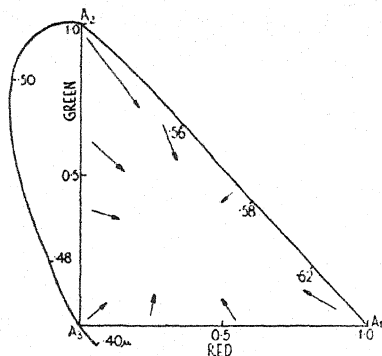


FIG. 73.—Colour triangle in terms of A_1 , A_2 and A_3 . Arrows show direction of errors caused by using negative emulsions with sensitivity curves that are all-positive transformations of C.I.E. distribution curves (W. D. Wright).

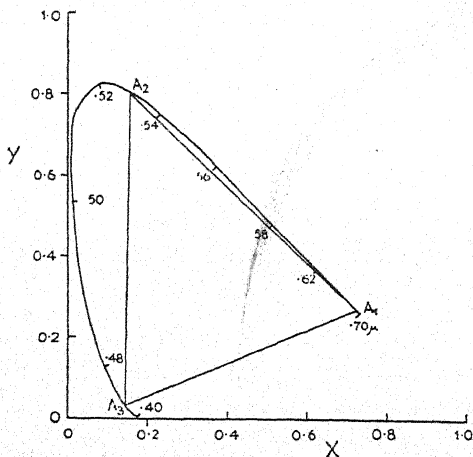
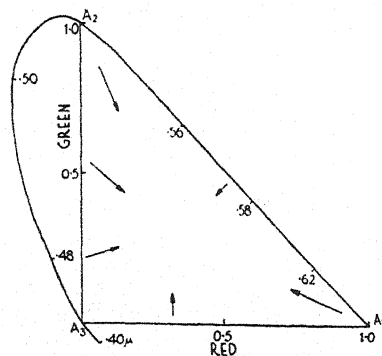


FIG. 74.—Direction of errors caused by using negative emulsion sensitivity curves that are similar to the positive portions only of the ideal sensitivity curves (W. D. Wright).

formations from the C.I.E. system. The main negative area belongs to the red primary and occurs in the blue-green part of the spectrum. Colours which radiate energy in this part of the spectrum will therefore be reproduced with too large a red component. The error trend is illustrated in Fig. 74, and corresponds mainly to a loss of saturation.

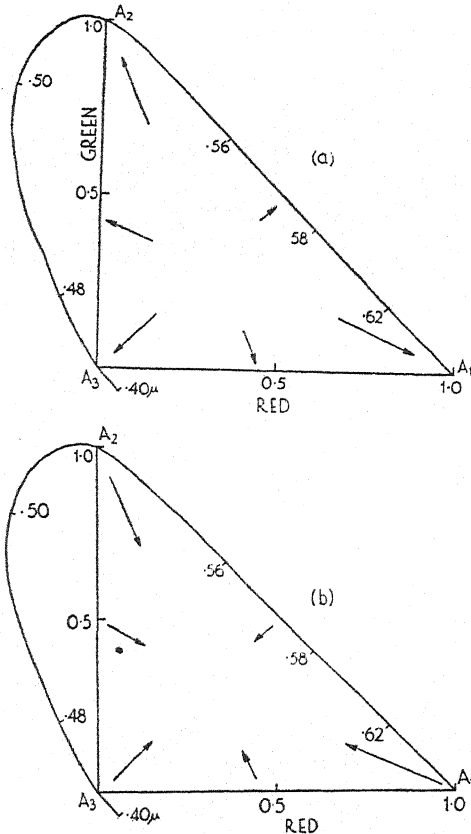


FIG. 75.—Direction of errors caused by (a) using a gamma greater than one, and (b) using a gamma less than one (W. D. Wright).

(3) “Errors caused by using sensitivity curves that are grossly different from the ideal curves, but still, of course, using A_1 , A_2 , A_3 as the reproduction primaries. It is impossible to deduce any general law in this case since the errors will depend entirely on the way in which the sensitivity curves depart from the correct curves. In any particular case the effect can be deduced by subtracting the theoretically correct curves from the actual curves; if a positive red area is left in the middle of the spectrum, greens and blue-greens will be too desaturated, and so on.

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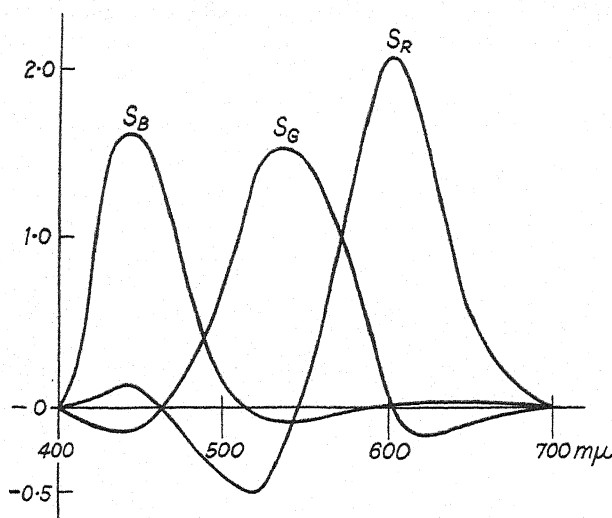


FIG. 76.—MacAdam's sensitivity curves for the calculation of reproduction of samples plotted in Fig. 77.

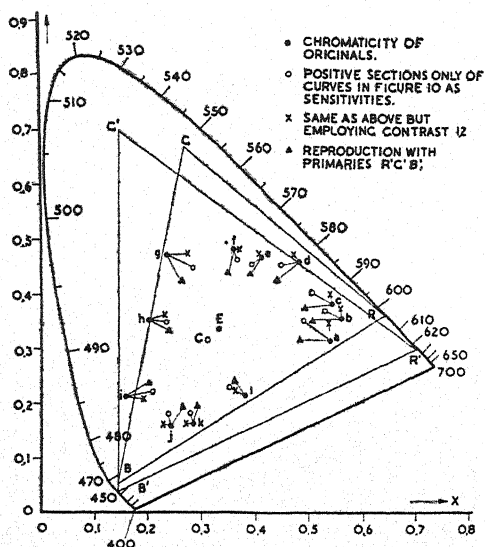


FIG. 77.—Calculated reproduction of 12 fairly bright pigmented paper samples. (D. L. MacAdam, *Journ. Opt. Soc. Am.*, 28, 399, 1938.)

(4) "Errors caused by using a gamma different from unity. If the gamma is greater than one, colours in which one primary tends to predominate over the others will be reproduced with the excess of that primary still further exaggerated. Colours will therefore change in hue and also become more saturated, in the sense indicated in Fig. 75. With a gamma less than one, the colours will change in the reverse direction and become more desaturated, as shown in Fig. 75A. (MacAdam (5))

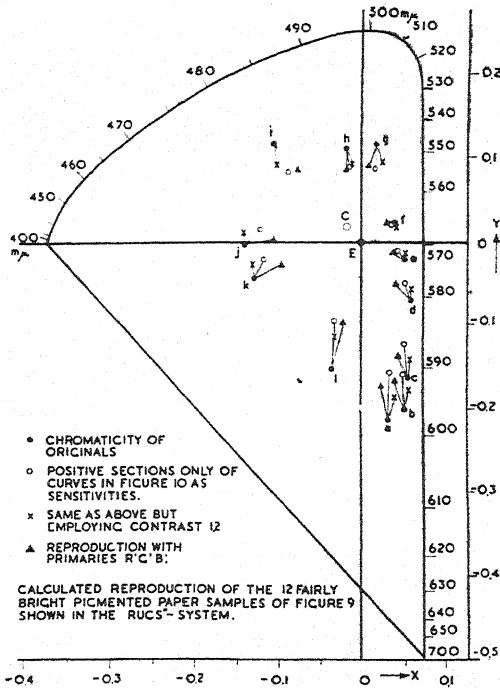


FIG. 78.

gives quantitative results for the effect of a change of gamma, and for certain of the other errors just described, Figs. 76, 77, 78.)

(5) "Errors caused by using the non-linear part of the characteristic curve. When the exposure extends to either the toe or shoulder of the characteristic curve, the effect is similar in trend to that of a gamma less than unity, the colours becoming strongly desaturated.

It is at once apparent that adjustment of the contrast of the photograph in order to produce some special effect is likely to be difficult if distortion of the colour rendering is to be avoided. Special methods must be adopted, such as the addition of a black and white emulsion

superimposed over the three colour components. The contrast of this extra layer can then be controlled to give any desired gamma to the overall picture, at a cost, of course, of loss of light and additional technical complications."

More by accident than by design the spectral transmission of filters (generally dyed gelatine) which have been used for colour photography from early times have exhibited a vignetted or trailing-off character instead of the sharp cut "water-tight compartment" form which the early workers supposed desirable (Fig. 69). Now these sloping, somewhat overlapping, curves when used in conjunction with the type of spectral sensitivity we can impart to an emulsion yield *effective spectral sensitivities* closely approximating the form of the distribution curves of the reproduction primaries, which is what is required. (See Table 25 for the transmissions of Wratten Tricolour Filters.)

The colorimetric specification of Wratten Filters 25, 58 and 47 is as follows:—

C.I.E. ILLUMINANT C

No.	X	Y	Z	X	Y	Dominant Wavelength	Excitation Purity %
25	·3028	·1425	·0001	·6805	·3193	615·3	100·0
58	·0891	·2451	·0219	·2500	·6885	541·5	86·8
47	·0862	·0240	·4730	·1477	·0412	461·3	96·8

The spectral transmission curves for this Wratten Tricolour set of filters are given in Fig. 79.

This is why the empirical trial of filters of different type of spectral transmission always yielded the best results with the slightly vignetted curves. This is especially true of additive systems in which reproduction primaries located in the spectrum locus are obtainable, thus yielding both a wide range and high saturation. (Certainly the red to green hues.) Given correct emulsion sensitivities the visual appearance of analysis primaries might depart radically from that of the synthesis primaries. In an integral tripack system of the negative positive type the emulsion sensitivities of the negative would be the all important consideration. Its ultimate coloration is of significance only in relation to the positive sensitivities. Conversely the colours of the positive are all important but its sensitivities are only of significance in relation to the coloration of the negative.

(b) Subtractive Synthesis

But in subtractive processes the failure is in the instrument we have to play upon with our modulators. Since the so-called subtractive process is in effect an additive process it is right to think of each

TABLE 25

Wavelength (Mu).						Wratten Filter No.		
						Transmission (%).		
						Red Filter No. 25.	Green Filter No. 58.	Blue Filter No. 47 (C.5).
400	..	..	..	..	..	—	—	25.1
410	..	..	..	..	..	—	—	35.4
420	..	..	..	..	..	—	—	49.0
430	..	..	..	..	..	—	—	49.5
440	..	..	..	..	..	—	—	48.0
450	..	..	..	..	..	—	—	47.8
460	..	..	..	..	..	—	—	43.7
470	..	..	..	..	..	—	—	37.4
480	..	..	..	..	..	—	1.97	30.3
490	..	..	..	..	..	—	11.5	21.8
500	..	..	..	..	..	—	30.3	12.5
510	..	..	..	..	..	—	50.1	5.42
520	..	..	..	..	..	—	60.2	1.30
530	..	..	..	..	..	—	54.7	0.15
540	..	..	..	..	..	—	39.0	—
550	..	..	..	..	..	—	30.2	—
560	..	..	..	..	..	—	25.1	—
570	..	..	..	..	..	—	17.0	—
580	..	..	..	..	..	0.16	10.0	—
590	..	..	..	..	..	10.2	5.63	—
600	..	..	..	..	..	50.1	2.82	—
610	..	..	..	..	..	70.0	1.35	—
620	..	..	..	..	..	80.5	0.57	—
630	..	..	..	..	..	84.0	0.21	—
640	..	..	..	..	..	85.5	—	—
650	..	..	..	..	..	87.0	—	—
660	..	..	..	..	..	87.0	—	—
670	..	..	..	..	..	87.0	—	—
680	..	..	..	..	..	87.0	—	—
690	..	..	..	..	..	87.0	0.10	—
700	..	..	..	..	..	87.0	1.97	—

subtractor in terms of the primary it is asked to absorb. If we plot on the C.I.E. chromaticity chart the primaries which are absorbed by typical subtractive dyes, we are horrified to find that they are located well inside the triangle (Fig. 80). Hence the obtainable colours will be limited in range and saturated hues will be inferior to those obtainable by the additive synthesis. The distribution curves which would modulate such reproduction primaries so as to equal the results of additive mixture of the reference primaries R. G. B. of the C.I.E. system would resemble those in Fig. 58. After all, while we can alter the percentage of each absorber present on a given occasion we cannot

alter its own nature. If we are given the ingredients for a salad dressing it is only possible to alter the proportions.

- i. An ideal instrument for tricolour synthesis by subtraction from white light would utilize three absorbers of variable density, each having its maximum absorption strictly limited to one third of the spectrum, for which third the other two absorbers would have to be perfectly transparent (Fig. 81). Note that if the trans-

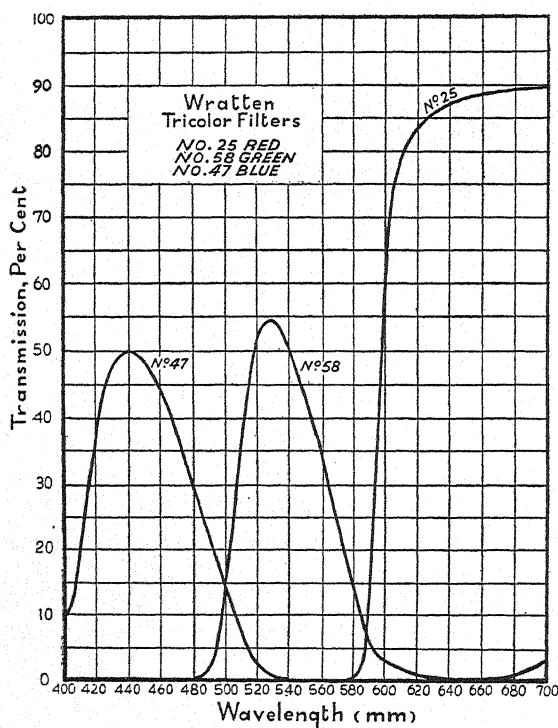


FIG. 79.—Spectral absorption curves of the standard Wratten tri-colour filters for colour photography.

missions were total of single wavelengths (viz., monochromatic), provided these were selected from the right regions, the instrument would still function satisfactorily, but the synthesis would be impractically low in lightness. Such filters are, of course, purely imaginary.

- ii. As has already been stated, three analyses of the recording light, each of which comprises wavelength by wavelength the spectral distribution of one of the reproduction primary stimuli, are used to modulate the densities of the three absorbers. One type of

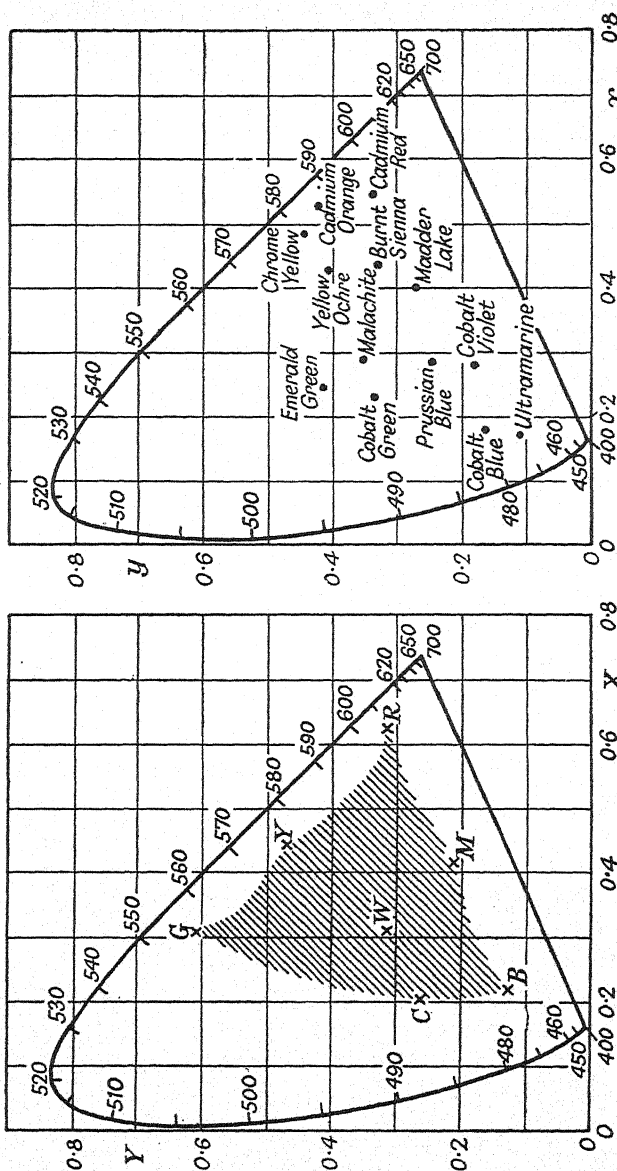


Fig. 80.—Chromaticity chart showing by the shaded area typical range of colours which can be reproduced in a three-colour subtractive process (W. D. Wright).

Fig. 80A.—Position on Chromaticity chart of well-known artist's pigments (W. D. Wright).

analysis may be the product of the spectral transmission of a filter and the spectral sensitivity of an emulsion (Fig. 56B), another may be an integral tripack in which the light may be analysed by the spectral sensitivity of one or other of the emulsion

layers without a filter. In practice the analysis may be a separation negative in which silver densities represent quantities of a primary stimulus, or alternatively the developed silver may be an intermediate agent in the production of a dye as in "colour coupling."

- iii. The subtractive *synthesis* is inefficient owing to the non-existence of stable dyes which conform to the requirements. For example, there is always failure to absorb completely the region desired and to transmit completely the correct wavelength bands (Figs. 82, 83, 84). Also decreasing densities of the dyes do not exhibit

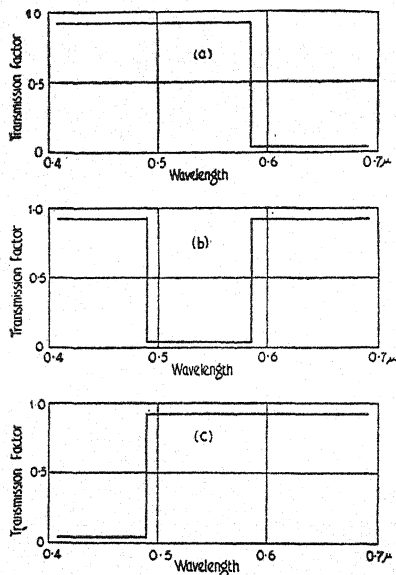


FIG. 81.—Ideal transmission curves of synthesis dyes in subtractive process necessary for the process to operate exactly as if it were an additive system. (a) Minus red dye. (b) Minus green dye. (c) Minus blue dye.

non-selective absorptions in the one-third region of the spectrum in which absorption should alone occur. In general the result is a compromise which is surprisingly effective when we consider the defects in the system.

Each ideal dye illustrated in Fig. 81 would control independently one strip of the spectrum constituting the synthesized colour. The three sections of the spectrum would correspond respectively to three additive primaries S_1 , S_2 and S_3 , and the colour synthesized is due to some additive mixture of these. Let us examine how actual dyes in subtractive mixture function additively. In Fig. 85 (from a paper by W. D. Wright) (2) the transmission curves of three dyes typical of commercial

processes are shown. Assume an incident beam of uniform spectral distribution of energy passes in turn through the dyes A, B and C. Without referring to the mathematical procedure suffice it to say that the energy distribution for the light transmitted by A, B and C can be derived (see Fig. 85). Its colour will be found by multiplying a set of

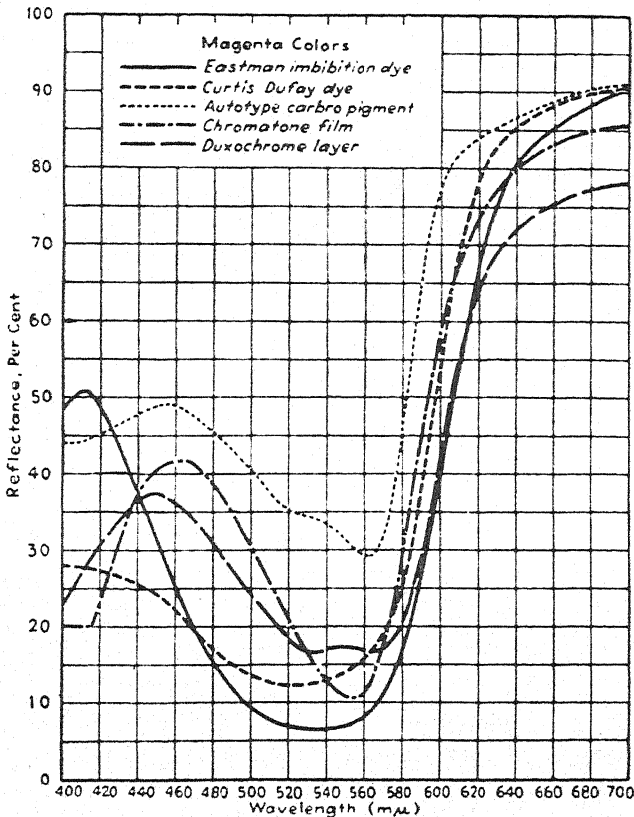


FIG. 82.—Spectral reflection characteristics of magenta colours of various manufacture.

distribution curves by curve D. The distribution curves might be the C.I.E. group or linear transformations of these, say of S_1 , S_2 and S_3 of Fig. 81. The product of curves D and E is shown in F, being the relative amounts of S_1 , S_2 and S_3 required to match the colour of the transmitted light, D. Unfortunately, a change of density of any one of the dyes affects the areas of *all three* of the distribution curves and, as Wright has shown, the extent to which the three areas will be affected

by changes in the density of one of the subtractive primaries will vary according to the densities of the other two.

The problem presents three aspects:—

1. We must seek primaries S_1 , S_2 and S_3 yielding the minimum errors if their subtractive mixtures are described as additive.
2. Determination of type of errors arising from defective primaries.
3. Having calculated required effective sensitivities to control S_1 , S_2 and S_3 as additive synthesis primaries, allowance must be made for imperfect curves and processing conditions.

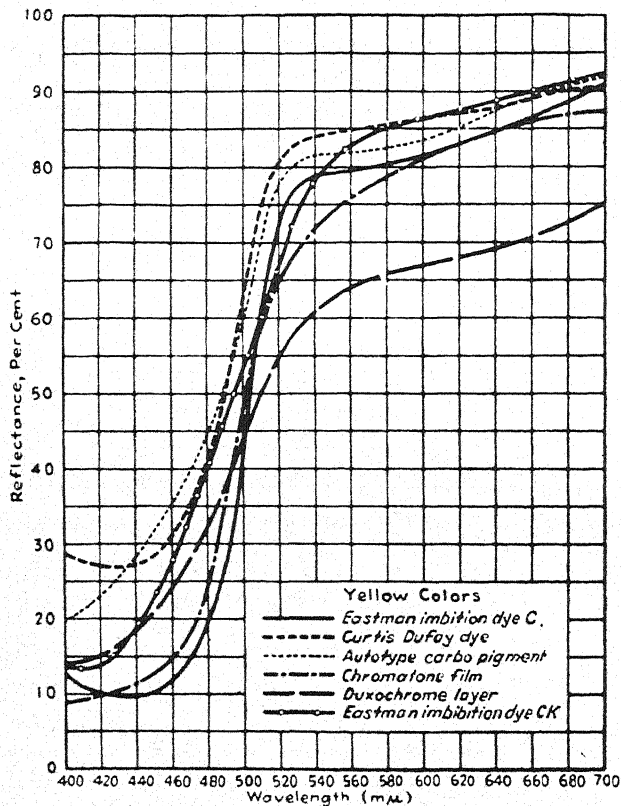


FIG. 83.—Spectral reflection characteristics of yellow colours of various manufacture.

Wright pointed out (2) that “each of the absorption curves A, B and C have a point of maximum absorption (minimum transmission) at a certain part of the spectrum.” Designate the mean positions of these absorption maxima by λ_1 , λ_2 and λ_3 . Each of the distribution curves has a maximum. Assume that these maxima also occur at or near to λ_1 , λ_2 and λ_3 . It follows that the areas of the distribution curves in the

neighbourhood of these wavelengths will do most to control the amounts of S_1 , S_2 and S_3 in the final colour. At first sight it looks as if the best way of separating the actions of the three dyes would be to describe this mixture in terms of three additive primaries S_1 , S_2 and S_3 , selected to provide a set of distribution curves whose maxima coincided in wavelength with the absorption maxima of the synthesis dyes. Unfortunately the distribution curves cannot be adjusted so as to make this method work.

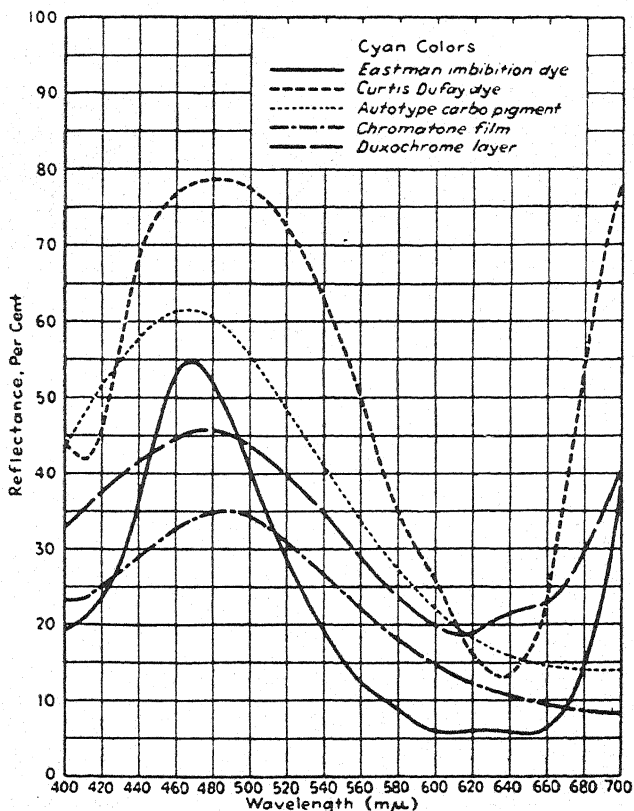


FIG. 84.—Spectral reflection characteristics of blue-green colours of various manufacture.

Wright shows in Fig. 86 distribution curves for three sets of reference primaries, which are linear transformations of the C.I.E. curves (Fig. 55) using the following primaries:—

- (1) 0.46μ , 0.53μ , 0.65μ .
- (2) 0.46μ , 0.53μ , 0.61μ .
- (3) 0.46μ , 0.55μ , 0.61μ .

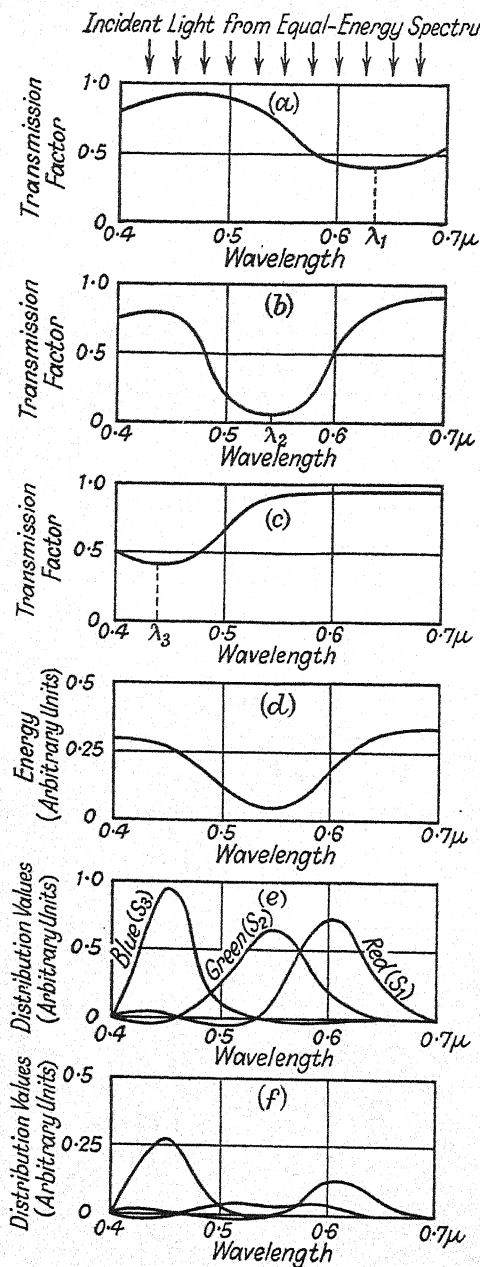


FIG. 85.—Diagram to illustrate the stages in the calculation of the colours resulting from the superposition of the three synthesis dyes in the subtractive process. Equal energy incident beam is assumed. (a) Transmission curve of minus red dye. (b) Transmission curve of minus green dye. (c) Transmission curve of minus blue dye. (d) Energy distribution of light after passing through (a), (b) and (c). (e) Distribution curves for equal-energy spectrum in terms of S_1 , S_2 and S_3 , the primaries in terms of which the colours of the subtractive process are to be described. (f) Distribution curves in terms of S_1 , S_2 and S_3 for the energy distribution shown in (d), obtained by multiplying curves (d) and (e) together (W. D. Wright).

Note that in each set the maxima are approximately 0.45μ , 0.54μ and 0.61μ . It chances that dyes of this type are fairly common in subtractive processes and for these cases the colour mixing should be described in terms of these wavelengths. The blue curve in each case is

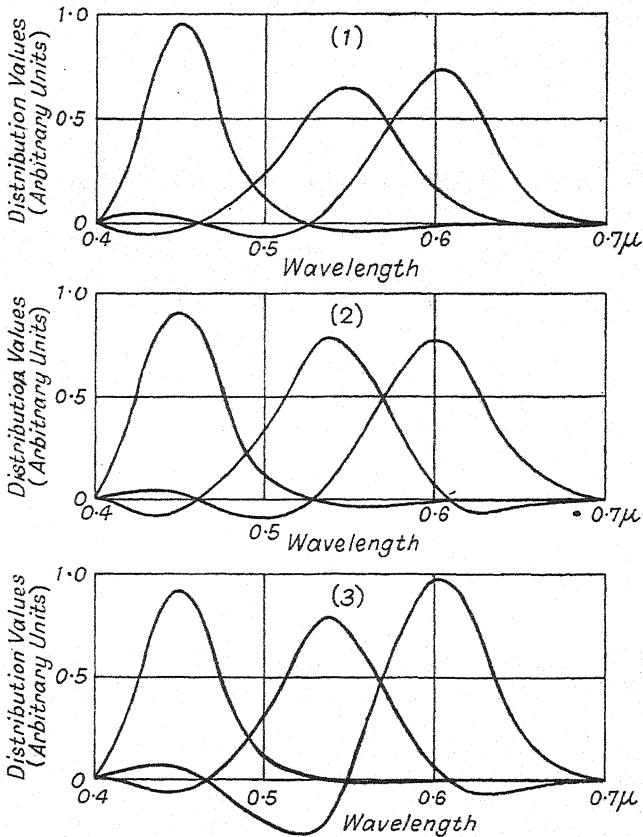


FIG. 86.—Distribution curves for three sets of reference primaries, namely, (1) 0.46μ , 0.53μ , 0.65μ . (2) 0.46μ , 0.53μ , 0.61μ . (3) 0.46μ , 0.55μ , 0.61μ (W. D. Wright).

more or less isolated and thus can be used in all cases as the best approximation for the equivalent additive primary. The red and green curves are impossible to separate owing to the invariable overlap in the yellow region. Wright says:

“Assuming then that the minus red and minus green dyes both transmit an appreciable percentage of the yellow and that the wavelengths of maximum absorption are at λ_1 and λ_2 , the colour rendering is

likely to be represented as an additive mixture to the closest approximation if the hypothetical additive primaries are taken at wavelengths somewhere between 0.61μ and λ_1 , for the red, and between 0.54μ and λ_2 for the green. The precise position is not likely to be of special importance and a value midway between the limits is the most obvious choice. The three primaries in the subtractive process that should be used to describe the colour reproduction in terms of additive mixture are therefore monochromatic radiations with wavelengths $\frac{1}{2}(\lambda_1 + 0.61\mu)$ Red, $\frac{1}{2}(\lambda_2 + 0.54\mu)$ Green, and 0.45μ Blue. (Some adjustment of these values might be called for if it were known that the photographs were to be illuminated with a light source having an energy distribution very different from that of an equal-energy spectrum.) Using these primaries the ideal spectral sensitivity curves for the negative emulsions can be

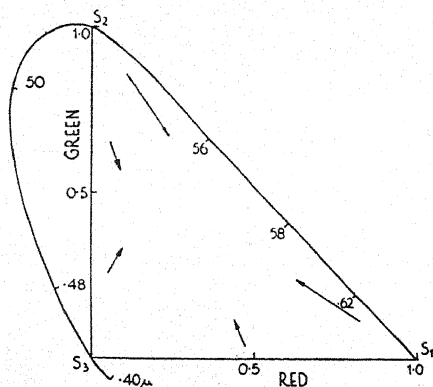


FIG. 87.—Colour triangle in terms of S_1 , S_2 and S_3 . Arrows show direction of errors caused by the fact that subtractive mixture does not behave exactly as additive mixture (W. D. Wright).

calculated and the error trends due to departure from the ideal curves can be determined.”

The subtractive process is not as effective as the additive because the difference between the ideal curves of Fig. 81 and the practical curves of Fig. 85 signifies that “when the density of filter B, say, is such that the light at wavelength λ_2 is effectively eliminated there is still transmitted a significant amount of light in the yellow and the blue-green. Similar tendencies will be shown by filters A and C. Reds will therefore tend to be reproduced as too orange, greens as too yellow-green, and so on; there will also be some tendency for the colours to become desaturated. The error trend is therefore of the type shown in Fig. 87. The magnitude of the error will vary with the density of the dye, becoming relatively smaller as the density increases. Any material departure of the transmission curves from the type of curve shown in

Fig. 85 can only be treated as a special case and the effect on the quality of reproduction analysed accordingly."

Figs. 73, 74, 75 and 85 all show errors directed inwards into the triangle, not necessarily towards the centre. Masking reverses this tendency and the use of sensitivity curves greatly different from any possible transformation of the C.I.E. curves could be made to reverse this direction, in certain parts of the colour triangle.

TABLE 26.—IDEAL RECTANGULAR PRIMARIES

(CLARKSON AND VICKERSTAFF)

(a) Primaries: 400-470 $M\mu$, 470-600 $M\mu$, 600-700 $M\mu$

Lightness.	10%		20%		40%		80%	
	x	y	x	y	x	y	x	y
Cyan ..	0.329	0.456	0.329	0.456	0.329	0.456	0.360	0.441
Magenta ..	547	233	547	233	512	300	456	380
Yellow ..	486	461	486	461	486	461	486	461
Red ..	689	309	689	309	580	352	472	390
Green ..	366	546	366	546	366	546	392	502
Blue ..	290	200	346	275	388	356	428	400

(b) Primaries: 400-490 $M\mu$, 490-580 $M\mu$, 580-700 $M\mu$

Lightness.	10%		20%		40%		80%	
	x	y	x	y	x	y	x	y
Cyan ..	250	466	250	466	250	466	384	426
Magenta ..	528	275	528	275	528	275	470	372
Yellow ..	504	473	504	473	504	473	504	473
Red ..	651	347	651	347	651	347	493	392
Green ..	299	648	299	648	299	648	412	464
Blue ..	250	182	320	260	390	342	432	392

(c) Primaries: 400-510 $M\mu$, 510-560 $M\mu$, 560-700 $M\mu$

Lightness.	10%		20%		40%		80%	
	x	y	x	y	x	y	x	y
Cyan ..	176	435	176	435	178	434	400	414
Magenta ..	497	332	497	332	497	332	476	364
Yellow ..	521	471	521	471	521	471	521	471
Red ..	609	391	609	391	609	391	508	402
Green ..	231	737	231	737	306	616	424	436
Blue ..	180	182	274	264	367	346	428	392

TABLE 27.—SLOPING-SIDED PRIMARIES
(CLARKSON AND VICKERSTAFF)

Steep Slope (see Fig. 89B)

<i>Lightness.</i>	10%		20%		40%		80%	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
Cyan ..	0.163	0.444	0.163	0.444	0.163	0.444	0.384	0.420
Magenta ..	537	245	537	245	524	280	464	380
Yellow ..	529	464	529	464	529	464	529	464
Red ..	674	326	674	326	630	346	484	400
Green ..	240	733	240	733	264	692	420	452
Blue ..	256	192	316	264	388	336	436	400

Gradual Slope (see Fig. 89C)

<i>Lightness.</i>	10%		20%		40%		80%	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
Cyan ..	116	318	116	318	220	412	400	416
Magenta ..	567	229	558	238	520	294	466	380
Yellow ..	562	438	562	438	562	438	562	438
Red ..	690	310	680	318	610	356	500	398
Green ..	224	738	258	686	356	552	424	442
Blue ..	276	206	324	276	396	352	436	398

TABLE 28.—DENSITY IN TRANSMITTING REGIONS (IDEAL RECTANGULAR PRIMARIES)

Complete transmission (see Fig. 91A)

<i>Lightness.</i>	10%		20%		40%		80%	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
Cyan ..	0.250	0.466	0.250	0.466	0.250	0.466	0.384	0.426
Magenta ..	528	275	528	275	528	275	470	372
Yellow ..	504	473	504	473	504	473	504	473
Red ..	651	347	651	347	651	347	493	392
Green ..	299	648	299	648	299	648	412	464
Blue ..	250	182	320	260	390	342	432	392

Unwanted Density 0.2 (see Fig. 91B)

Lightness.	10%		20%		40%		80%	
	x	y	x	y	x	y	x	y
Cyan ..	250	466	250	466	269	464	402	422
Magenta ..	651	347	651	347	651	347	473	376
Yellow ..	504	473	504	473	504	473	504	473
Red ..	651	347	651	347	651	347	495	396
Green ..	299	648	299	648	316	626	424	449
Blue ..	312	232	360	290	408	356	438	392

Unwanted Density 0.4 (see Fig. 91C)

Lightness.	10%		20%		40%		80%	
	x	y	x	y	x	y	x	y
Cyan ..	250	466	250	466	308	449	412	418
Magenta ..	651	347	651	347	651	347	474	376
Yellow ..	504	473	504	473	504	473	504	473
Red ..	651	347	651	347	651	347	495	398
Green ..	299	648	304	640	354	576	430	425
Blue ..	362	268	396	312	426	364	442	396

As far as lightness reproduction is concerned, Wright has pointed out that this must obviously be governed by the shape of the characteristic curve of the overall process as in black-and-white photography. Correct rendering of lightness values will depend upon the degree to which the negative sensitivities approximate to the ideal curves. In those parts of the spectrum where the ordinates are higher than they should be, the lightness will be too high and *vice versa*. This is particularly so in the subtractive process owing to its inability to equal the additive process in the independence of control of its primaries. It can be seen that any absorption overlap would tend to reproduce that part of the spectrum with too low a lightness, and failure of the absorption bands to meet would give too high a lightness value in that part of the spectrum. Wright states that the error will be of a similar type in the case of actual as compared to ideal absorption curves, but will naturally be modified by the more gradual slope of the absorption curves and will also vary to some extent according to the densities of the dyes.

Clarkson and Vickerstaff (6) examined the possible gamut of colour reproducible by hypothetical subtractive synthesis primaries and by the

primaries of Technicolor and Kodachrome. Comparisons were made of the merit of three sets of imaginary primaries consisting of spectral divisions into three rectangular and contiguous ideal absorptions. The cuts were at (a) 470 $M\mu$, 600 $M\mu$; (b) 490 $M\mu$, 580 $M\mu$; (c) 510 $M\mu$, 560 $M\mu$. A maximum optical density of 2.0 was assigned to the standard strength of the primary dyes. Absorption curves at four different strengths having densities in the absorbing regions of 2.0, 1.0, 0.5 and 0.25 were converted to transmission curves, and then by the weighted ordinate method into chromaticity co-ordinates in Illuminant A. By plotting x and y separately against the lightness, curves were constructed from which the chromaticities at lightness levels of 80, 40, 20 and 10% were

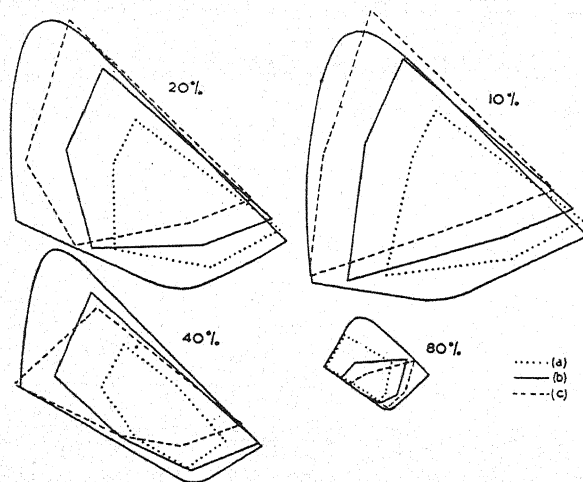


Fig. 88.—Hypothetical rectangular primaries (Clarkson and Vickerstaff).

could be plotted (Table 26, Fig. 88). Set (c) is preferred and it is noted that this set is in agreement with conclusions of previous workers.

Real dyes differ from the ideal in having (1) sloping absorptions and (2) absorption in the wavelength range requiring to be completely transmitted. The relative importance of these two effects was assessed first by comparing the triplets shown in Fig. 89 with the ideal. The slopes were adjusted to intermeet at half the maximum density at 490 and 580 $M\mu$, so that the total density of an equal mixture of the primaries was constant across the spectrum. Treated as before the results are shown in Table 27 and Fig. 90. It is apparent that at low lightness levels the vignetted primaries control an area in excess of the vertical sided primaries. This is due to the fact that the purity of a green, say, cannot exceed the colour represented by the complete waveband 490-580 $M\mu$, while a green of approaching 100% purity results from high concentrations of yellow and cyan at, say, 535 $M\mu$. At higher

lightnesses of 40%, sloping primaries (c) were inferior but primaries (b) still have the advantage. At 80% the differences are negligible. Wright has pointed out that with sloping sides to the curves and overlapping, a change of concentration in one dye would be apparent in a part of the spectrum where it should not be. The significance of the second characteristic of real dyes (namely, unwanted absorptions) is

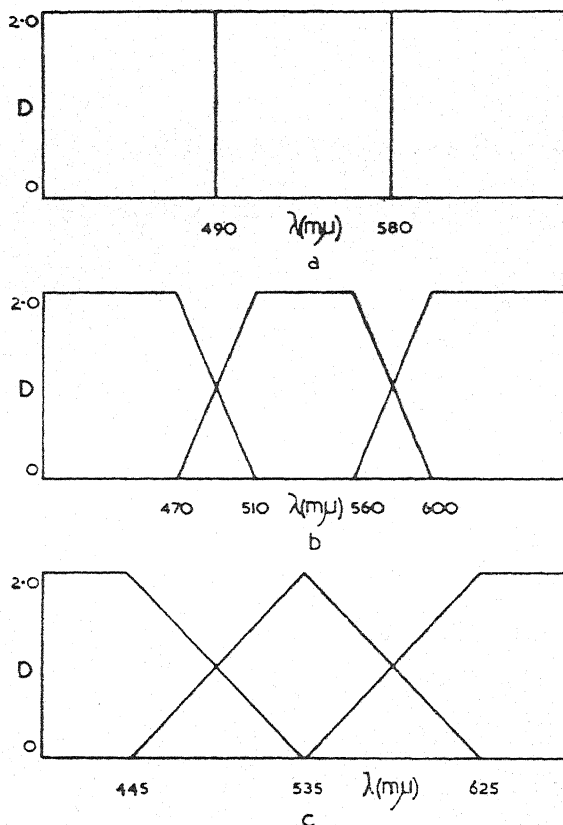


FIG. 89.—Sloping-sided rectangular primaries (Clarkson and Vickerstaff).

next considered. In Fig. 91, since dyes are common with ideal transmission beyond $500 M\mu$, yellows are given as fully transmitting beyond $500 M\mu$. The cyan is assumed to have zero density between 400 and $580 M\mu$, and a density of 2.0 from 580 – $700 M\mu$, and is compared with others having densities of 0.2 and 0.4 in the 400 – $580 M\mu$ region. Again, with the magenta it is assumed that it is completely transparent to wavelengths higher than $580 M\mu$. Table 28 and Fig. 92 give the results. The chromatic area shrinks at all lightness levels as the unwanted density

increases. The conclusions are that "primary dyes for a subtractive process should have absorption bands covering approximately the ranges 400-450 $M\mu$, 450-580 $M\mu$, and 580-700 $M\mu$. The absence of absorption in transmitting regions is more important than steep sides

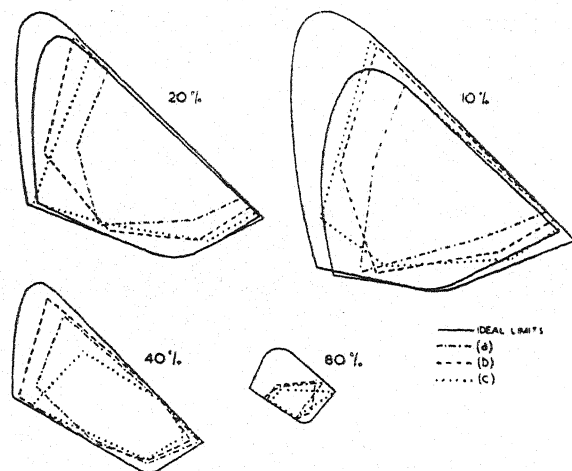


FIG. 90.

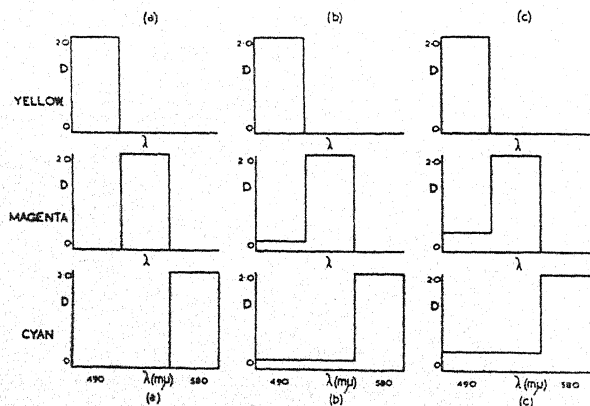


FIG. 91.—Hypothetical primaries absorbing in nominally transmitting regions (Clarkson and Vickerstaff).

to the absorption bands, and should provide one of the main criteria in the selection of dyes for colour photography.

The behaviour of Kodachrome was examined. Reproduction of real colours was measured. Noting that Friedman's curves (7) for the Kodachrome primaries show a background density of about 0.2, this

value was subtracted from all three curves at every wavelength. The curves were then multiplied by a factor sufficient to give a maximum density of 2.0, and from these basic curves, density curves at full, half,

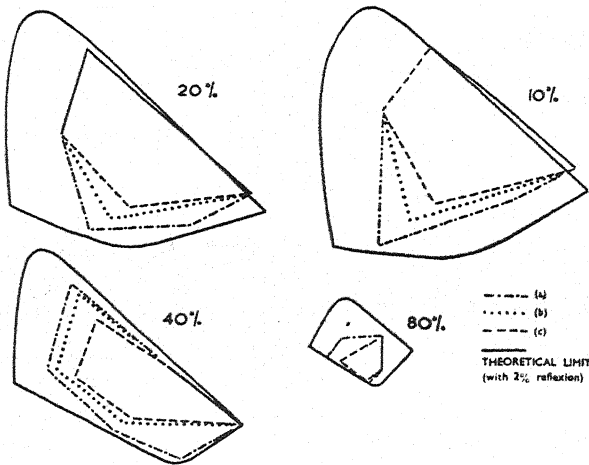


FIG. 92.—Hypothetical primaries absorbing in nominally transmitting regions (Clarkson and Vickerstaff).

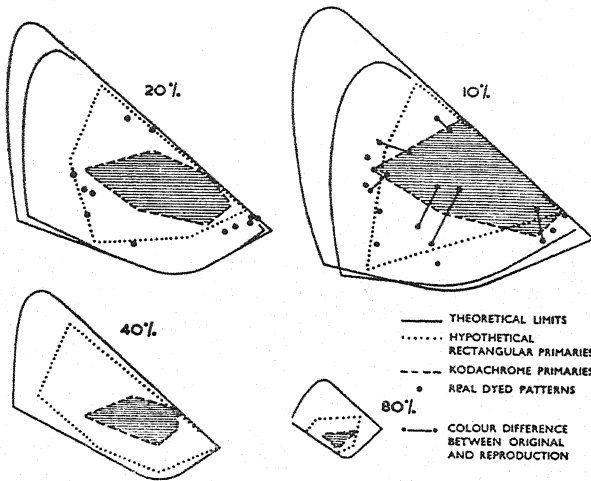


FIG. 93.—Kodachrome primaries (Clarkson and Vickerstaff).

quarter and one-eighth strength of the three primaries and their binary mixtures were constructed and, as before, converted via the transmission curves to chromaticity co-ordinates. The results at different lightness levels are given in Table 29 and Fig. 93.

TABLE 29.—(CLARKSON AND VICKERSTAFF)
Kodachrome Primaries (Friedman)

<i>Lightness.</i>	10%		20%		40%		80%	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
Cyan ..	0.224	0.412	0.252	0.416	0.340	0.418	0.420	0.412
Magenta ..	572	256	524	300	492	344	458	388
Yellow ..	580	414	580	414	580	414	508	428
Red ..	660	324	612	356	546	380	474	400
Green ..	416	526	432	494	442	498	446	421
Blue ..	368	306	402	348	426	378	440	398

The diagram also contains points representing reproduced colours of high saturation dyeings of materials. The area covered by ideal primaries is also shown and the small volume of the colour solid Kodachrome covers relative to ideal primaries will be observed. Maximum defects are at high lightness levels.

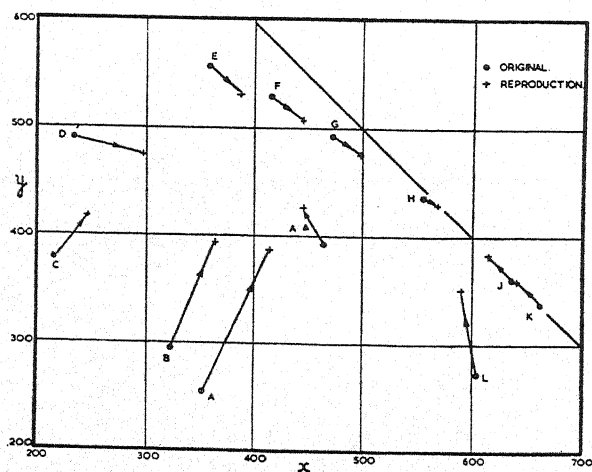


FIG. 94.—Chromaticity Errors, Kodachrome "A" (Clarkson and Vickerstaff).

Clarkson and Vickerstaff have drawn attention to the fact that the Kodachrome primaries approach most closely to the ideal primaries in the cyan, magenta and yellow regions, because in these regions only one dye is involved. When two dyes are present together to give red, green or blue colours, the densities of each dye in nominally transmitting regions add together and produce serious degradation. In confirmation

woollen patterns dyed in saturated colours and covering the spectrum were photographed on Kodachrome A by an illuminant of 2,700° K. A neutral step wedge was included and a range of exposures made in each pattern. Table 30 gives the results and Fig. 94 the chromaticity errors. Reds and magentas become yellower, greens yellower, blues greener. Deep blues are greyer. As the authors point out, the reproduction is minus blue and this is borne out by the character of the published curves of Kodachrome primaries. The purity is less for all colours and worst for blue. Except in one case, the reproduced lightness is lower in relation to white than in the original, but the ratio of the apparent lightnesses varies from pattern to pattern showing three minima at C, H and M, which are cyan, yellow and magenta in colour respectively. These colours have been reproduced by one of the subtractives only and as there is negligible absorption overlap the high lightness is explicable.

TABLE 30.—(CLARKSON AND VICKERSTAFF)
Kodachrome Reproduction

Pat- tern.	Colour.	Original.			Reproduction.				$\frac{L}{L^1}$
		<i>x</i>	<i>y</i>	Light- ness <i>L</i> .	<i>x</i>	<i>y</i>	Light- ness.	Relative Lightness <i>L</i> ¹ .	
A	Blue-violet	0.353	0.255	4.6	0.413	0.388	0.83	4.1	1.1
B	Blue	325	295	8.1	363	393	1.13	5.6	1.5
C	Blue-green	217	379	12.1	248	417	2.0	9.8	1.2
D	Blue-green	235	489	9.9	299	473	0.54	2.6	3.8
E	Green	358	554	18.8	387	530	0.47	2.3	8.2
F	Green	415	527	25.3	445	506	1.52	7.5	3.4
G	Yellow-green	472	491	33.2	498	474	2.61	12.8	2.6
H	Yellow	555	435	47.2	568	428	7.8	38.5	1.2
J	Orange	640	359	33.8	616	384	3.65	18.0	1.9
K	Orange-red	662	337	24.4	640	360	2.7	13.3	1.8
L	Red	652	325	21.8	634	368	3.4	16.7	1.3
M	Magenta	604	270	14.9	591	350	3.43	16.9	0.9

Technicolor reproduction range has been calculated by the same workers (see Table 31).

Fig. 95 shows the chromaticity range of Technicolor and Kodachrome primaries and the position of some real dyed fabrics. Obviously Technicolor primaries have much the larger range and can reproduce most of the patterns. In fact, they compare favourably with ideal primaries. The diagram sets forth the advantages of imbibition dyes compared with the dyes so far obtainable by colour development.

TABLE 31.—TECHNICOLOR PRIMARIES (CLARKSON AND VICKERSTAFF)

<i>Lightness.</i>	10%		20%		40%		80%	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
Cyan ..	0.160	0.340	0.226	0.376	0.318	0.402	0.424	0.406
Magenta ..	662	270	600	282	516	326	460	392
Yellow ..	576	420	576	420	576	420	534	448
Red ..	700	300	660	328	580	370	468	400
Green ..	310	610	354	554	404	476	440	418
Blue ..	330	270	378	322	420	356	448	400

Irrespective of practical colour processes Clarkson and Vickerstaff investigated how closely existing dyes approach the ideal. Dyes were sought in which half the maximum density was reached at 490 and 580 $M\mu$ respectively, with the steepest possible slope. They selected for

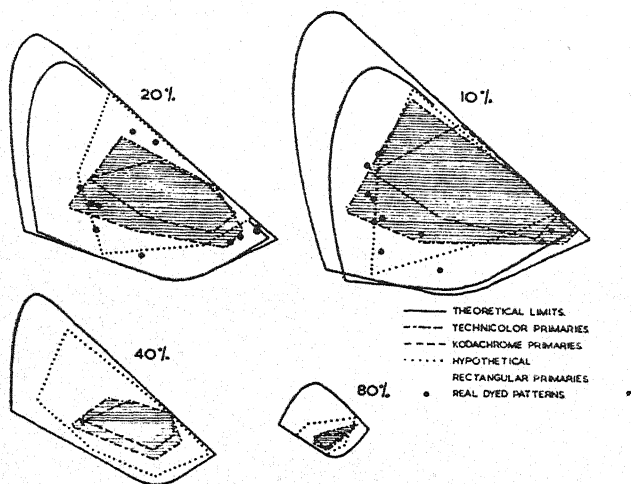


FIG. 95.—Technicolor primaries (Clarkson and Vickerstaff).

yellow, Metanil Yellow YK (C.I.138). For the magenta, an experimental dye known as Experimental Minus Green. For cyan, Filter Blue Green, which has splendid absorption in the far red, and high transmission for green and blue. The absorptions are given in Fig. 96. The colour range of the best set is given in Table 32 and the range in Fig. 97.

These dyes are superior to any subtractives at present in use in any process and the authors from this take heart for the future of subtractive processes in general, but there is good reason to doubt the validity of

their conclusion that sloping-sided primaries are to be preferred on purely theoretical grounds to rectangular ideal primaries, since only with such primaries could there exist a linear relation between each of

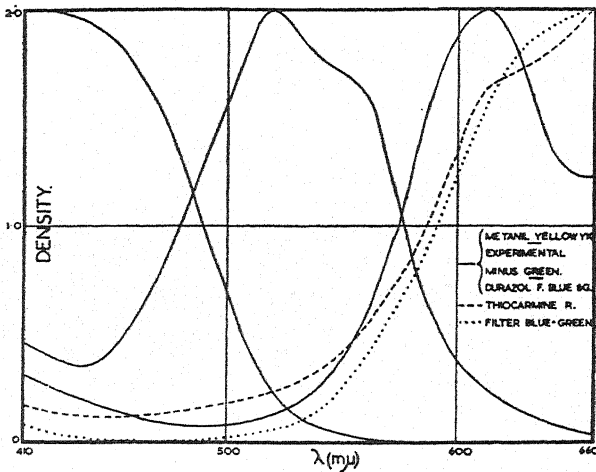


FIG. 96.—Absorption curves of some dyes (Clarkson and Vickerstaff).

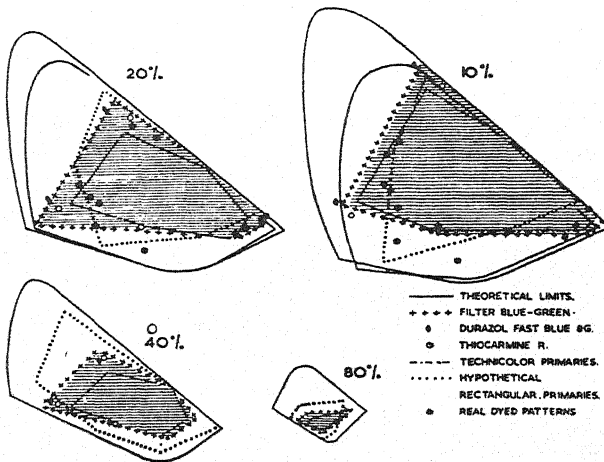


FIG. 97.—Real dye primaries (Clarkson and Vickerstaff).

the emulsion responses and the concentration of minus dyes in the reproduction.

A. Dresler (8), Hoermann and Schultze, Leiber and others, have investigated the reproduction by Agfacolor negative-positive and

TABLE 32.—METANIL YELLOW YK, EXPERIMENTAL MINUS GREEN, FILTER BLUE-GREEN (CLARKSON AND VICKERSTAFF)

<i>Lightness.</i>	10%		20%		40%		80%	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
Cyan ..	0.126	0.232	0.150	0.330	0.250	0.406	0.400	0.416
Magenta ..	680	264	606	284	538	324	466	386
Yellow ..	541	448	541	448	541	448	541	448
Red ..	704	296	658	320	598	370	480	401
Green ..	296	674	332	620	384	540	432	436
Blue ..	340	264	380	314	416	366	438	396

reversal film of light filters, pigments, leaves and flowers. The reversal film gave slightly better reproduction than the negative-positive process. Coloured light sources as the subject show larger chromaticity distortion than pigments, due to the transmission curves of filters displaying steeper absorptions and narrower cuts than the spectral reflections of the pigments. Faulty lightness reproduction is often serious. From a pictorial standpoint it is more important to achieve accuracy of the tonal scale (relative lightness) than to make any sacrifice of lightness accuracy to hue or saturation, in both of which considerable inaccuracy is tolerable without exciting the least attention from the vast majority of individuals who constitute the motion picture audience.

A. Marriage (9) pointing out that the effective spectral sensitivities of taking materials in general do not conform to theoretical mixture curves for practical reasons, suggests that masking should preferably be such as to give an accurate reproduction of three selected colours in the original, one of which should be a non-selective neutral and set forth a method of calculating the required masking. He chooses for the three colours, a non-selective neutral flesh colour and grass green. He ultimately concludes that "by using with the green filter negative two masks, one from each of the other two negatives, we can obtain a reproduction nearly correct in hue, with the contrast increased to 1.33 and with grey added to those colours which had a high absorption in the green." The mathematically inclined reader is referred to the original paper for a pleasant afternoon's recreation.

To sum up then, the law is that a primary subtractor must be a perfect transmitter (or reflector) of approximately two-thirds of the spectrum range, and that it must have preferably a sharp boundary to its selective absorption. We have seen that this law is by no means to be kept with materials at our disposal and unless masking is resorted to the deficiencies are as follows:—

Deficiencies

Magentas	Reflect (or transmit) the red region well, but insufficient of the blue; and their absorption of the green region is not complete.
Yellows	Approximate reasonably well to the requirements, but they do not completely absorb blue and violet of which 10% is often reflected (or transmitted).
Cyans	Are poor or very poor reflectors (or transmitters) of green, and inefficient for blue. Neither do they by any means entirely absorb the red region they are in theory required to do.

Effects

Reds	} Reproduce well.
Oranges	
Yellows	
Greens	Are rendered too dark; too brown; too desaturated.
Blue-Greens	Are rendered too dark, too blue; often purplish; too desaturated.
Blues	Are rendered too dark; too purple; too desaturated.
Purples	Brownish.

And the distortion may be even greater in desaturated tones of these hues.

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(c) Printing Additive Films (Réseau or Mosaic Type)

From the earliest days of screen "plates" copying has been found to be a very tough problem. Before an additive process like Dufaycolor could be announced as a practicable process for motion pictures, the peculiar difficulties of copying had to be surmounted.

Negative-positive processing of Dufaycolor film was first described by G. B. Harrison and D. A. Spencer in their paper delivered before the Royal Photographic Society in 1936. They first emphasize that in the past mosaic or screen processes in which the emulsion is coated direct on to the taking screen had required to be processed by reversal for the following reasons:

1. If a negative were first obtained it would be necessary to make prints, an operation of great difficulty for a variety of reasons.
2. The cost of making one positive by the negative-positive process is greater than by direct reversal, though the cost of making a number is the same.
3. Copies by the negative-positive process have hitherto been inferior to copies by reversal from reversed originals.

Previous attempts to make negative-positive prints had resulted in prints so degraded as to be useless. Spencer (*Phot. Journ.*, 1933, p. 19) had drawn attention to the effects of light scatter within the emulsion (or "irradiation"), with the result that light which had passed through, say, the red elements of the réseau gave an eventual silver deposit extending beyond the red element. In reversal this negative image is removed, and in so far as the spreading causes partial uncovering of the neighbouring screen elements the final colour will be desaturated. This effect is worse in a reversal copy. Moreover, the spectral overlap of the elements increases the desaturation. Scattered light, then, reduces saturation by reduction of density difference between adjacent elements. This effect would be equally present either in a reversal copy or a negative-positive copy.

It is here that the "colour contrast effect" becomes operative. Silver bromide solvents in the first developer of a reversal process have, amongst other properties, the following important function:

The development processes occurring opposite two adjacent colour elements influence one another in such a way that any inherent density difference is exaggerated. This effect tends to reduce density differences. Over a considerable range of densities the colour contrast effect is greater than the scatter. But this effect is peculiar to the reversal process and is not present if a mosaic material is developed in a normal developer. If a silver solvent such as ammonia is present in a negative developer, the resulting image is foggy and stained with silver.

Clearly the ideal in a negative-positive screen process is that light

passing through a given colour element renders emulsion only immediately underneath that element developable. Unsatisfactory solutions of the problem were:

1. The intensification of partially developed images to ensure that the image is built up mainly from the more fully exposed grains (most successful from the point of view of the result obtained).
2. The division of processing into ten stages to permit of the removal of the surface image (poor).
3. The use of low potential developers such as caustic hydroquinone. Many of the irradiated grains have received less than the threshold exposure, but the results, although vivid in colour, are too contrasty.

Experiments were then carried out with active developers containing sodium thiosulphate—the “simultaneous developer fixers”—reasoning that, “*in fixation, diffusion of fresh supplies of fixing agent into the emulsion from the bulk of liquid is more important than is the case with development—particularly when, as in caustic metol, the latter is extremely vigorous. One can, therefore, picture fixation as proceeding layer by layer through the film, the outermost layers, owing to their nearness to the bulk of the solution, fixing out first.*”

In the race between development and fixation, therefore, it was hoped that the layers nearest the support would receive preferential development relative to those nearer the surface. Later it was thought that the thiosulphate functions as a retarder of surface development.

Harrison and Spencer stated that the particular value of thiosulphate is believed to depend on the fact that whereas in relatively small concentrations it slows down development, in still smaller concentrations it actually accelerates development, and, as a result, it is possible with a properly balanced developer to cause the majority of development to take place in the depths of the emulsion.

Thiosulphate does not, apparently, give rise to the colour contrast effect to any detectable extent. Traces of soluble iodides or sulphides will also produce depth development.

The optimum concentration of thiosulphate depends to some extent upon the emulsion coating weight.

The advantages of negative-positive processing of Dufaycolor are:

1. Simplified processing.
2. Control of contrast in both negative and positive by varying development time.
3. Improvement in sound due to:
 - (a) Sound is printed direct from sound negative without intermediate positive.

- (b) Positive material is similar to normal positive motion picture film and therefore of relatively high gamma.
- 4. The positive print is projected the normal way round, obviating re-focusing of the picture, and the sound track need not be printed through the base.
- 5. Absence of exaggerated colour.
- 6. More accurate rendering of hue.
- 7. Negative and positive emulsion resembling black-and-white practice, with more latitude in the negative, and greater maximum density in the positive.
- 8. Greater tranquillity on the screen.
- 9. The use of a standard processing machinery.

In the successive reversal process the two stocks, master positive and projection positive, give similar gammas on reversal, the gamma in each case being somewhat under 1.0 (diffuse gamma). With the negative-positive process it has been possible to use a negative material having the same speed as the reversal material, but under the normal development conditions having a gamma of about 0.65 and exposure range of over log. $E=3.0$. The printing material is similar in speed to normal positive and has a gamma of about 1.70. The overall gamma of these materials is therefore about 1.1 and the latitude in the negative is sufficient for all normal outdoor and studio requirements.

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- KODAK LIMITED, *The Photography of Coloured Objects*, 10th edition, p. 86.
 NEWTON, A. J., *Brit. Journ. Phot.*, 53 (1906), p. 406.
 BULL, A. J., OLIVER, L. W., and SPENCER, D. A., *Phot. Journ.*, 73 (1933), p. 358.
 HARRISON, G. B., and SPENCER, D. A., "Negative-Positive Processing of Dufay-color Film," *Phot. Journ.*, 77 (1937), p. 250.

6. PROJECTION LIGHT-SOURCE

The distribution of energy in the source of light used for projection of a colour film is a factor requiring the most careful consideration, since the colour film is but a modulator of this energy and a small difference in the energy of the different frequencies will require marked changes in the modulator. Attempts are being made to standardize the screen illumination both as to quality and quantity. So far recommendations have dealt only with luminance.

Both low and high intensity carbon arc sources have been used with both reflector and condenser type of optical systems for the projection of 35 mm. motion pictures in theatres. The low intensity carbons with a condenser lens optical system have practically become obsolete in motion picture projection though they are used sometimes for theatre spot lamps. The low intensity carbon arc with a reflector system is also

becoming obsolete. The white light needed for modern coloured pictures can only be obtained from the high intensity carbon arc. Two different forms of high intensity arcs are used with the two different types of optical systems. The original form of the high intensity carbon arc employed a plain rotating positive carbon with the negative electrode placed at an angle below the positive axis as shown in Fig. 25. This is widely used with a condenser lens optical system which picks up the radiation from the positive crater and focuses it on the film aperture in the projector. The other form of the high intensity arc employs a pair

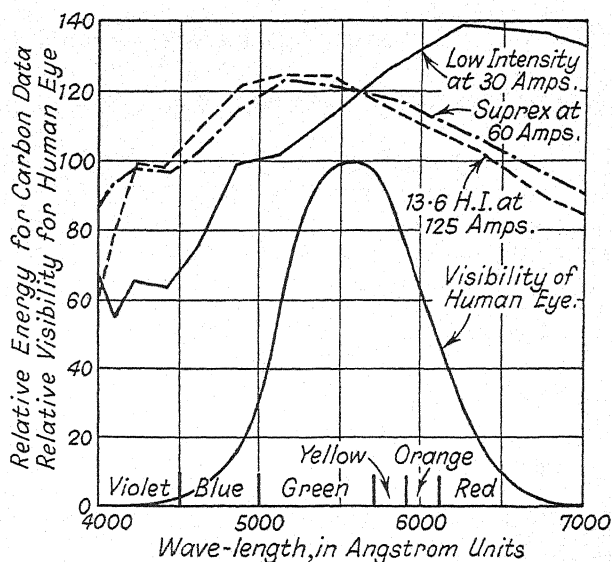


FIG. 98.—Spectral energy distribution data for light at centre of projection screen with low-intensity lamp at 30 amps., Suprex-type lamp at 60 amps. and condenser-type lamp at 125 amps. with heights of curves adjusted to give equal foot-candles (Null, M. R., Lozier, W. W. and Joy, D. B., *Jour. Soc. Mot. Pict. Eng.*, March 1942).

of copper coated non-rotating carbons burned coaxially with their common axis coinciding with that of an elliptical reflector which focuses the light from the crater upon the film. In either case the image of the positive crater is focused on the film aperture and this in turn is focused on the projection screen by the projection lens. The light output on the projection screen with various typical projection systems and carbon combinations is shown in Table 33.

The spectral energy distribution data for light at the centre of the projection screen is shown in Fig. 98 for a low intensity system and two common high intensity combinations.

The radiant energy intensity at the centre of the film aperture is given in Table 34 for several typical projection systems. Relative

amounts of energy in the various wavelength bands are also shown. The intensity ranges from 0.35 watts per sq. mm. for a low intensity arc to more than 1 watt per sq. mm. for the most powerful high intensity arc. The high intensity arcs have relatively twice as much of their total energy in the visible region as the low intensity arc and are therefore cooler sources.

Ideal Source

So long as the spectrum is continuous it would be possible for the processing laboratory to balance the three-colour printing in order to compensate for excess of blue or red in the projection light, as the case might be. But the laboratory is faced by the disappointing fact that the picture is destined to be projected by a great diversity of lights.

Suppose that we take as our standard for laboratory control an illuminant approximating a Planckian radiator at a temperature of 5,300° K., then we would probably be quite safe in the average theatre equipped with high-intensity projection, but the projected picture would be lacking in blue when projected by low-intensity arcs. It is probable that carbon manufacturers could make a carbon giving a somewhat more even distribution of energy, but the present units are very good indeed. A far greater source of trouble than any defects in the carbon characteristics is to be ascribed to faulty projection.

We can only stress the extreme importance of this final stage in the transformation process we have traced. The situation is an exact parallel to radio broadcasting. Enormous efforts are expended to ensure that the technique of transmission is all that science and money can do to make it perfect. By means of apparatus of great complexity the symphony concert is radiated into space. But if it is "picked up" by an indifferent receiver the last link in the chain may nullify all the efforts previously made—the hearer may receive only a dim idea, a distorted impression, of what the original sound was really like. Similarly, the projection arc and the optical system of the projector are an absolutely vital link in a technical chain. It is *essential* that the producer of the colour film should not have his colour distorted—indeed, just as essential as that the picture should be in focus.

We have not space to enlarge upon the important factor of the optical system used in the various makes of projector now in general use. Projection systems may be divided into three categories.

1. Mirror arcs (Fig. 99).
2. Condensing lens.
3. Mirror arc and condensing lens combined.
 - A. Rotating positive.
 - B. Non-rotating (hand fed).

TABLE 33.—SCREEN ILLUMINATION WITH CARBON ARC MOTION PICTURE PROJECTION SYSTEMS
(ZAVESKY, GERTISER AND LOZIER)

35-mm. Film Projection Systems—0.600-in. \times 0.825-in. Aperture

Item	Carbon.		Arc.	Lamp Optical System.	5.5-in. E.F. $f/2.5$ Untreated Lens.			5-in. E.F. $f/2.0$ Treated Lens.				
	Positive.	Negative.			80% Dist.		Max. Light. ²		80% Dist.		Max. Light. ³	
					Screen Lumens. ¹	% Dist. ²	Screen Lumens.	% Dist.	Screen Lumens.	% Dist.	Screen Lumens.	% Dist.
1	Low Intensity 12 mm. \times 8 in. Low Int. "One Kilowatt," D-C	8 mm. \times 8 in. Low Int.	32	55	10 in. Dia. $f/2.3$ Mirror	—	—	—	—	3,400	70	
2	7 mm. \times 12 or 14 in. "Suprex" Non-rotating High Intensity	6 mm. \times 9 in. "Orotip" "C"	40	27.5	11½ in. Dia. $f/2.5$ Mirror	4,600	80	5,900	80	6,500	65	
3	7 mm. \times 12 or 14 in. "Suprex"	6 mm. \times 9 in. "Orotip" "C"	42	33	14 in. Dia. $f/2.3$ Mirror	4,900	80	6,600	80	7,500	60	
4	7 mm. \times 12 or 14 in. "Suprex"	6 mm. \times 9 in. "Orotip" "C"	50	37	14 in. Dia. $f/2.3$ Mirror	6,400	80	8,600	80	10,000	60	
5	8 mm. \times 12 or 14 in. "Suprex"	7 mm. \times 9 in. "Orotip" "C"	60	36	14 in. Dia. $f/2.3$ Mirror	7,600	80	10,300	80	11,000	65	
6	8 mm. \times 12 or 14 in. "Suprex"	7 mm. \times 9 in. "Orotip" "C"	70	40	14 in. Dia. $f/2.3$ Mirror	9,600	80	13,000	80	14,000	65	
7	Rotating High Intensity 13.6 mm \times 22 in. High Int.	1½ \times 9 in. "Orotip" "	125	68	Condenser Lenses at $f/2.0$	7,500	80	11,500	80	14,500	60	
8	13.6 mm. \times 22 in. High Int. ⁴	1½ \times 9 in. "Orotip" "	150	78	Condenser Lenses at $f/2.0$	11,000	80	16,000	80	19,500	60	
9	13.6 mm. \times 22 in. Super-High Int. ⁴	1½ \times 9 in. Heavy Duty "Orotip" "	170	75	Condenser Lenses at $f/2.0$	11,000	80	18,500	80	20,500	60	

NOTES: 1. Screen lumen figure is for systems with no shutter, film, or filters of any kind.

2. Per cent. distribution refers to ratio of light intensity at side of screen to that at the centre.

3. Maximum light is value with system adjusted to produce maximum light intensity at the centre of the screen.

4. Heat filter may be necessary; reduce light approximately 20% if Aklo or Phosphate glass is used

TABLE 34.—RADIANT ENERGY INTENSITY AT CENTRE OF FILM APERTURE
(ZAVESKY, GERTISER AND LOZIER)

Item.	Carbons.		Arc.		Lamp Optical Systems.	*Total Energy Flux at Aperture Centre Watts per sq. mm.	Measured % of Total Energy Flux in Indicated Spectral Regions.				Calculated % of Total Energy
	Positive.	Negative.	Amps.	Volts.			Below 6,300A	6,300-11,250A	11,250-42,000A		
1	12 mm. L.I. Proj.	8 mm. L.I. Proj.	32	55	10½ in. Dia. f/2.3 Mirror	0.35	20	37	43	24	
2	7 mm. "Suprex "	6 mm. " Orotip " C	50	37	14 in. Dia. f/2.3 Mirror	0.55	39	33	28	48	
3	8 mm. " Suprex "	7 mm. " Orotip " C	70	40	14 in. Dia. f/2.3 Mirror	0.65	44	31	25	52	
4	13.6 mm. H.I. Proj.	⅞ in. " Orotip "	125	68	Condensers at f/2.0	0.75	40	36	24	48	
5	13.6 mm. H.I. Proj.	½ in. " Orotip "	150	78	Condensers at f/2.0	0.95	40	38	22	—	
6	13.6 mm. S.H.I. Proj.	½ in. H.D. " Orotip "	170	75	Condensers at f/2.0	1.05	41	38	21	—	

* No projector shutter or filters and carbon position and lamp optical system adjusted for approximately maximum centre screen light.

Each of these types has its peculiarities. Maladjustment of mirror and arc, wrong choice of carbon combinations, incorrect focusing of the arc image on the gate, and other faults, can profoundly modify the distribution of light upon the screen and the general colour balance. Most mirror arcs give an image on the screen which is concentrated in brightness in the centre and which falls off towards the edge. There are little data to go on, but there is probably considerable variation in the colour quality of the light in different parts of the screen. The distribution varies continually. The light may at one moment be blue-violet white, and at the next it may be greenish in its dominant hue.

To sum up:

1. The processing laboratory must have a standard white light for viewing the work.
2. The projection illuminant for the colour film must be standardized.

7. THE SCREEN REFLECTOR. THE REPRODUCTION PLANE

There is little to be said about screens save that they should be white, whereas they are often very dirty, and sometimes yellowish.¹ The polar curve of the diffusely reflected light should be as evenly distributed as possible. Beaded screens or those giving semi-specular reflection are undesirable as being unfair to members of the audiences seated beyond the narrow maximum angle of reflection.

The American Standards Association have adopted the following standard of screen luminance (see ASA.—Z22.39—1944).

“The brightness (luminance) at the centre of a screen for viewing 35 mm. motion pictures shall be $10. \pm 1$ ft. lamberts when the projector is running with no film in the gate.”

Colour of the Light on the Projection Screen

As we have observed, the carbon arc is still by far the most usual source of light used for the projection of motion picture film. Recent developments by the British Thomson-Houston Company of compact-source high-pressure mercury-cadmium vapour discharge lamps give promise of providing, perhaps before very long, an alternative possessing important advantages, and no doubt such sources will be used for theatre projection with as much success as they have attained for studio illumination. We have seen that the existing carbon arcs are of two kinds, low intensity and high intensity. These two differ considerably in their distribution of energy—enough to make a print colour-balanced for high intensity lack blue if projected with low

¹ They frequently absorb 25 per cent. of the incident light, and sometimes much more.

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intensity, and similarly a print balanced for low intensity will be much too blue and lacking in red if projected with high intensity.

Chief points affecting the colour of the light on the projection screen, assuming no film in the gate, are:

1. Type of arc lamp—viz., low intensity or high intensity.
2. Type of carbon—viz., emission spectra of the elements present in the core.
3. Selective absorbance by the optical system.
4. Selective absorbance by the screen.
5. Adjustment of arc position relative to the optical system.

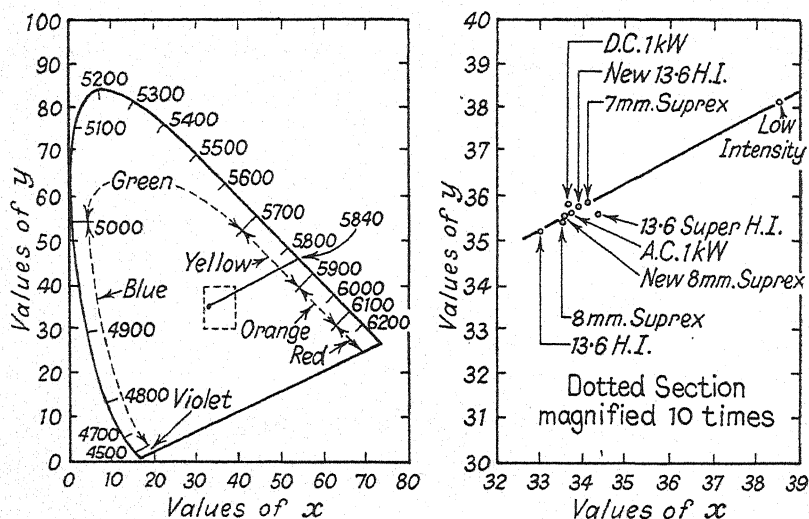


FIG. 100.—Chromaticity diagram showing C.I.E. colour-co-ordinates of various lamp and carbon combinations. The right-hand figure shows a tenfold enlargement of the indicated portion of the left-hand figure (Null, M. R., Lozier, W. W. and Joy, D. B., *Journ. Soc. Mot. Pict. Eng.*, March 1942).

Interesting data were presented by M. R. Null, W. W. Lozier, and D. B. Joy, of the National Carbon Company, U.S.A. They measured the spectral energy distribution of the light at the centre of the projection screen for a number of arc lamp and carbon combinations. It is known that the fifth factor in the above list is the chief cause of lack of uniformity in both colour and brightness over the whole area of the screen. But for these measurements the carbon was maintained at the correct position. In Fig. 98 we have the spectral energy distribution over the visible range of radiation incident upon the projection screen for three widely used types of arc lamp—viz., low-intensity "Suprex" and true high intensity at 125 amperes. The three curves are adjusted for equal luminosity. It will be observed that the low-intensity lamp

TABLE 35.—COLOUR MEASUREMENTS AT CENTRE OF SCREEN WITH COMPLETE OPTICAL SYSTEM; CARBONS POSITIONED TO GIVE UNIFORM VISUAL COLOUR OVER SCREEN

Trim.	Lamp and Optical System.*	Amps.	I.C.I. Trichromatic Colour Co-ordinates.		Colour-Temp. at Centre of Screen (°K.).	Colour-Temp. of Bare Arc† (°K.).
			x.	y.		
12-mm.—8-mm. SRA	Low-Intensity Lamp and Mirror } " 1 KW." D.C. Lamp and Mirror " 1 KW." A.C. Lamp and Mirror	30	0.3853	0.3800	3,870	3,570
7-mm. "Suprex" Pos.		40	0.3370	0.3584	5,300	
6-mm. "Orotip" "C" Neg.		52	0.3380	0.3532	5,260	
7-mm.—7-mm. "Suprex" Pos.		59	0.3375	0.3560	5,300	
	"Suprex" Lamp and Mirror	65	0.3346	0.3554	5,420	
7-mm.—6-mm. "Suprex" ..		42	0.3452	0.3638	5,020	5,800
		45	0.3408	0.3583	5,180	
		50	0.3486	0.3660	5,060	5,950
8-mm.—7-mm. "Suprex" ..	"Suprex" Lamp and Mirror High-Intensity Lamp and Condensers	65	0.3364	0.3554	5,340	
		70	0.3386	0.3612	5,270	
13.6-mm. H.I. Proj.		125	0.3288	0.3445	5,600	
		145	0.3392	0.3576	5,240	

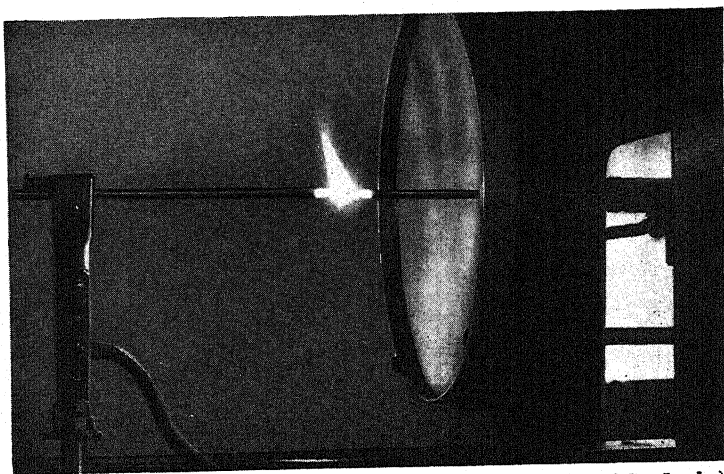
* All lamp mirrors and condensers were of comparable manufacture by the same maker. The projection lens was 5.5 in. *f*/2.5.

† Values for crater radiation (M. R. Null, W. W. Lozier, and D. B. Joy, *Journ. Soc. Mot. Pic. Eng.*, March 1942, p. 219).

exhibits a marked maximum in the red region, whereas the high-intensity lamps have a relatively even distribution of energy with a slight preponderance in the green. Trichromatic co-ordinates have been plotted on the C.I.E. (I.C.I.) chromaticity chart for a number of lamp and carbon combinations (Fig. 100). Table 35 gives the trichromatic co-ordinates of the whole range of light-sources studied. Referring the measurements to the locus of Planckian radiators, it is noted that the colour-temperature of the screen light for a low-intensity lamp is $3,870^{\circ}$ K., while the high-intensity screen light ranges from $5,020^{\circ}$ K. to $5,620^{\circ}$ K. Owing to the close correspondence of carbon arcs to "black body" sources, colour-temperature is a good indication of spectral energy distribution. Fig. 98 shows the spectral energy distribution of the low-intensity "Suprex" and condenser-type high-intensity screen light in comparison with spectral energy distribution curves for black bodies at the same colour-temperature and same candle-power. It will be seen that the spectral energy distribution of the screen light from the low-intensity lamp corresponds quite closely through the visible spectrum to that of a black body at the same colour-temperature.

The authors of this paper say: "In Table 35 are shown also colour-temperatures obtained in the earlier measurements on the direct crater radiation from some of these arcs. This has been unaltered by transmission through any optical system, and comparison of these values with our values for the colour-temperature of the screen light gives interesting information on the changes of colour produced by the optical systems of the particular projection lamps used. With the low-intensity lamp and the condenser-type high-intensity lamp the colour-temperatures of the light on the screen show relatively small departure from that obtained on the bare sources. The low-intensity lamp shows a little higher colour-temperature for the light on the screen compared to the bare source, and the condenser-type high-intensity lamp shows slightly lower colour-temperatures on the screen. With the 7-mm. and 8-mm. 'Suprex' positive carbons the colour-temperature of the bare source ranged from $5,800^{\circ}$ K. to $6,400^{\circ}$ K. These light-sources show a colour-temperature through the optical system on the screen 800° K. to 900° K. lower than the bare sources."

The main conclusions to be derived from the data are first that there is a very big difference between the distribution of energy of the low-intensity arc and that of the high-intensity, large enough to warrant the statement that a colour print balanced for one cannot be satisfactory if projected by the other, and vice versa. In practice the Technicolor and Dufaycolor laboratories balance their prints for a high-intensity projection illuminant and overlook the distortions which must inevitably occur in theatres still equipped with low-intensity lamps.



(By kind permission of Chas. H. Champion and Co., London)
FIG. 99.—Horizontal arc lamp.

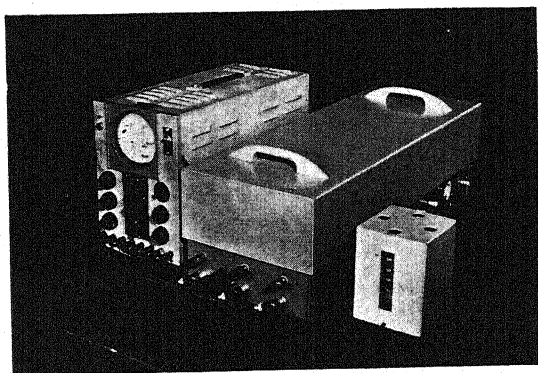


FIG. 101.—Morgan Colour Comparator.

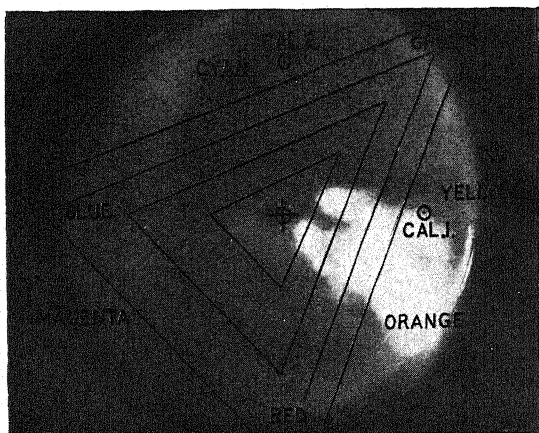


FIG. 103.—Oscillograph Screen of Morganite Colour Comparator.

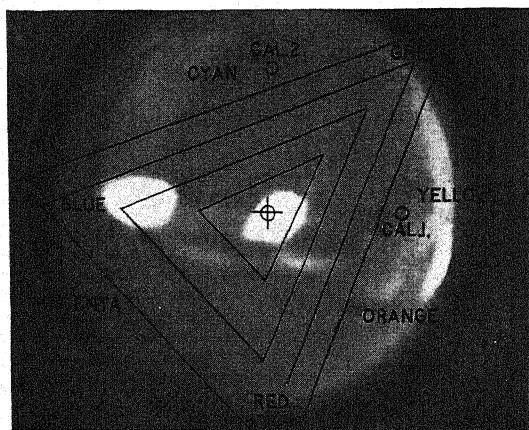


FIG. 104.—Ten-minute record of Morganite Colour Comparator.

The effect of a stained or yellowish screen may be extremely marked in selectively absorbing blue light in the projected image and the loss cannot be properly appreciated without a simultaneous comparison.

An Indicating Colour Comparator

D. M. Neale, of the Morgan Crucible Company Ltd., has described a very interesting apparatus for direct indication of small differences in the colour of the whites emitted by carbon arc lamps. Successive measurements of red, green, and blue content proved cumbersome and elaborate. Unstable light-sources meant that a variation of 5 per cent. in the light intensity during the taking of the readings would produce a corresponding error in the calculated colour. It became evident that some device was required which would fulfil the following requirements:

(1) An indication of the colour should be given continuously, and it should be given upon a triangular colour chart; this would enable transient phenomena to be investigated.

(2) The instrument should have the highest possible sensitivity, in order that near-whites might be compared with precision.

(3) Changes in brightness should not affect the magnitude of the deflection for a given colour.

(4) The instrument should be stable in operation without requiring readjustment or "balancing up" for each reading.

(5) It should be possible to compare different light-sources without having to move either a heavy instrument or the lamps themselves.

These requirements are met in the colour comparator as follows (Fig. 101):

(1) A cathode ray oscillograph enables the indication to be presented on a two-dimensional scale or diagram where it is continuously visible.

(2) Maximum sensitivity is obtained by comparing the *differences* in the proportions of red, blue, and green light from the source.

(3) An automatic gain control device is fitted in an electronic amplifier to compensate for brightness changes.

(4) Stability is obtained by using an A.C. amplifier.

(5) The measuring head of the instrument is small and portable, and is connected to the amplifier and oscillograph by several yards of cable.

The comparator head, which measures only 5 in. by 5 in. by $6\frac{3}{4}$ in. contains a motor-driven drum shutter which revolves in front of three photocells mounted behind tricolour filters. These photocells deliver to the amplifier three small voltages pulsating at about 70

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cycles per second. Three separate amplifiers, each having a maximum gain of about 106 db. (250,000 : 1), are mounted on the one chassis. Like the colour calculator, this comparator also operates on the "equal green" principle already mentioned, and includes an automatic gain control whereby the gain of each amplifier is made inversely proportional to the intensity of the incident green light. This enables brightness changes to be ignored over a useful range; thus if the light intensity falls to half its original value, the scale of the colour chart on the oscillograph remains the same and is not reduced. A meter on the side of the chassis indicates whether the instrument is operating within the range covered by the automatic compensation. If the illumination is outside this range the com-

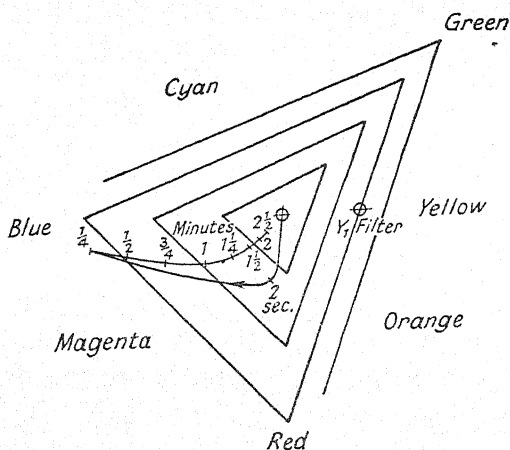


FIG. 102.—Change of colour with time after sudden reduction of current from 150 amps. to 135 amps. (high-intensity arc). (Courtesy of Morgan Crucible Co. Ltd.)

parator head is moved to or from the light-source until approximately the required level is obtained. It would be possible to provide virtually complete compensation for brightness changes but for the fact that the characteristics of the photo-cells used are linear only within certain limits.

Controls are provided on the chassis for making the centre of the colour chart represent any "near-white" light which is being investigated, and switches are also provided for calibration purposes and for halving the scale of the diagram when markedly different light-sources (e.g., "white flame" and "panchromatic" carbons) are being compared.

When the comparator is operating at maximum sensitivity each concentric triangle on the colour chart represents 5 per cent. colour saturation, zero saturation being at the centre of the diagram. Full-

scale deflection then represents about 20 per cent. saturation. Since the instrument is intended to be used as a colour comparator, as opposed to a colorimeter, it should be recognized that these percentages refer to a purely arbitrary scale which it has been found convenient to use in the laboratory. On this scale the standard Y-1 filter, used to correct a high-intensity arc to match daylight, is indicated as 15 per cent. yellow.

The new comparator has already proved of great value in the examination of carbon arcs used for studio lighting. As an example of the type of information which may be obtained by this unusually flexible instrument may be quoted Fig. 102, in which are recorded the transient colour changes resulting from a sudden reduction by 10 per cent. of the current in a high-intensity arc. The immediate effect is a pronounced fall in total light and a considerable colour change. As the crater "burns in" to the new shape required by the lower current, however, the light partially recovers and the colour almost completely returns to its original value. In the diagram it will be seen that in the first ten seconds the colour changes to about 17 per cent. blue-magenta and during the next two and a half minutes gradually recovers to a value of 3 per cent. magenta.

This shows that if a light of a constant colour is required on a studio set it is more important to obtain a steady line voltage—even 10 per cent. below the optimum—than to maintain approximately the correct voltage at the expense of instability. From this point of view, therefore, it would be a bad practice to readjust the line voltage immediately before taking a shot. Any adjustments should be made two minutes or more before shooting.

The above is only one example of the many types of useful investigation which are made possible by the new colour comparator. In conjunction with a steady reference source the instrument can also be used to measure the colour of glasses, diffusing screens, and colour correction filters.

An important application of the new instrument has been the measurement of colour stability and average colour of different types of arc. By taking a time exposure of the cathode ray tube a record is obtained which shows at a glance the limits of colour variation and the proportion of time during which the arc is producing light of a particular colour. Figs. 103 and 104 were produced in this way. The use of this technique has permitted a considerable acceleration of the development of improved carbons for specific colour purposes.

Luminance Factor of the Projection Screen

C. G. Heys-Hallett, of Mole-Richardson (England) Ltd., has made an exhaustive study of the screen luminance of British cinemas. He has developed an instrument known as the Morganite Reflectometer.

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The instrument is available in portable form or it may be permanently mounted in the projection box, where it can be used by the projectionist to standardize the screen luminance in a given theatre. The instrument consists of a small camera unit embodying a lens which throws an image of the screen on the target of a photoelectric cell. The image being smaller than this target, the galvanometer with which the camera unit is connected gives a continuous indication of the total amount of light collected by the lens from the screen. A disc bearing light filters is mounted immediately in front of the photoelectric cell, so that by rotating it, any desired filter may be inserted in the path of the light. A slide is provided between the photocell and the filter wheel in which suitable masks may be inserted. The instrument may be used to measure both the quantity and the colour of the light reflected either from the whole or any part of the screen. It is also obviously capable of measuring the reflected light from any surface—*e.g.*, for testing screen materials.

Correction of Readings

Service work is invariably carried out with the reflectometer mounted in the operating box, and it is most desirable that these readings should be comparable for the purpose under review. Early attempts to correct these readings by calculation failed, owing to inaccurate data. It was found that the great majority of operators would, when asked, immediately state the throw and screen dimensions, but usually state them wrongly. Success has, however, been obtained by using one dimension which can readily be checked by the service engineers—that is, the focal length of the lenses. This method has enabled a considerable amount of data, obtained in the ordinary course of their work by the service engineers of British Thomson-Houston Company and Morganite, to be placed at the disposal of the Committee of the British Standards Institution, when the question of standardization was under consideration. The method operates as follows:

The readings taken in the box are called “reflectometer readings,” and are corrected by the expression—

Reflectometer reading $\times 0.163 f$ = screen luminance factor, where f is the focal length of the lenses and the constant 0.163 contains the dimensions of the gate.

The screen luminance factor obtained from this formula is the reading which would be obtained if the reflectometer had actually been mounted in the axis of the beam at a distance from the screen equal to three times its width. The screen luminance factors for different cinemas are directly comparable, because, were they to be obtained directly with the reflectometer, the image on the photoelectric cell would be of constant size. The instrument could therefore be calibrated to read directly in foot-lamberts, but attempts to do so led to

TABLE 36.—TYPICAL CONDITIONS (C. G. HEYS-HALLETT)

Case.	Class of House.	Db.	Specific Brightness.*	Specific Red.	Specific Blue.	Remarks.
31	Large West End ..	-2.84	0.52	0.99	1.02	} Change due to retreatment of screen Modern arcs underloaded Same box equipment as 91, but fully loaded A.C. high intensity Low intensity
16	Large West End ..	+0.83	1.21	0.98	1.08	
95	Large West End ..	+2.18	1.65	1.03	1.28	
91	Modern large town ..	-0.97	0.80	1.05	1.05	
89	Modern large town ..	-1.19	0.76	0.77	1.1	
		-0.86	0.82	0.91	0.82	
74	Small country town ..	-1.08	0.78	0.93	1.5	Same equipment as 89 Beaded screen Low-intensity arcs Obsolete arcs
75	Small country town ..	-5.53	0.28	1.7	0.5	
93	Suburb ..	-7.96	0.16	--	--	
86	West End news theatre	+9.35	8.60	--	--	
56	West End news theatre	+6.46	4.43	0.87	0.85	
87	Renter's theatre ..	-5.00	0.314	1.77	0.77	
96	Renter's theatre ..	+8.23	6.65	--	--	
36	Studio rush room ..	+6.88	4.87	1.02	0.78	
14	Two rush rooms in same studio ..	+2.23	1.67	--	--	
15 f		+4.17	2.61	--	--	
37	Colour film laboratory	+4.18	2.62	1.70	0.71	{ As found After adjustment with reflectometer
A.12		+0.61	1.15	1.0	1.08	
A.16	Cinemas in Sydney and Melbourne	-6.20	0.24	--	--	Dirty screen, modern lamps
A.19		-0.09	0.98	--	--	
A.60		+3.01	2.0	--	--	
		-2.29	0.59	--	--	A.C. high intensity

* "Specific Brightness" is taken as 1=5.0 foot-lamberts.

confusion and were abandoned. Photometrical units are unfortunately very complicated, and quoting foot-lambert values, which are usually about half the value of the incident light in foot-candles, leads to endless explanations which frequently leave the exhibitor worse off than before.

"Specific Brightness"

The primary function of the figures which we are discussing is to convey an impression as to the excellence, or otherwise, of the projection, and this end can best be obtained in the following manner.

A large number of readings obtained in cinemas was examined, and a weighted average worked out by eliminating all freaks and very obsolete equipment, and this average, corresponding to a "screen brightness" of 60, was adopted by the Morgan Crucible Company as standard. All instruments are calibrated on the same bench, and the scale divisions have been used as purely arbitrary units. Actually, the standard corresponds to an average luminance factor of about 5 foot-lamberts. The screen luminance is always expressed as a function of this standard, and the result is termed the "*specific brightness*" of the cinema.

Example.—Cinema using 4½-in. lenses.
 Reflectometer reading: 20 units.
 Screen brightness = $20 \times 0.163 \times 20.25 = 66$.
 Specific brightness = $\frac{66}{60} = 1.1$.

This cinema is therefore 10 per cent. above standard. Each instrument is provided with a diagram (Fig. 105) from which the specific brightness may be read.

It is realized, of course, that the response of the human eye is, like that of the ear, logarithmic, but it is considered that over the relatively small range of brightness encountered in the problem under discussion a linear method of expression is the most suitable.

Table 36 shows readings taken in a number of representative cinemas, and indicates the wide variation encountered in practice.

Directivity of Screen

It is necessary to investigate the behaviour of the screen in all directions, and it was in connection with the preparation of polar curves for typical screen surfaces that difficulties were encountered, it being found that a number of factors affected the shape of the polar curves as measured. Some paints fluoresce to a measurable extent, and the intensity and type of light used in the test may therefore be important. The relative positions of light-source, screen, and reflectometer also affect the observed distribution.

The luminance factor of a perfectly diffusing surface is dependent on the incident luminous flux and the nature of the surface, and

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it is not affected by movement of the viewer to or from the screen; but if the screen surface acts as a reflector, the amount of light received by the eye of the observer will vary as the inverse square of the sum of the distance of the eye to the screen and of the screen to the light-source.

Commercial screens are rarely perfect diffusers, and the shape of the polar curve may therefore be expected to vary according to the method of test.

Polar curves were measured in the laboratory and care was taken to imitate cinema conditions. A high-intensity arc was used together with

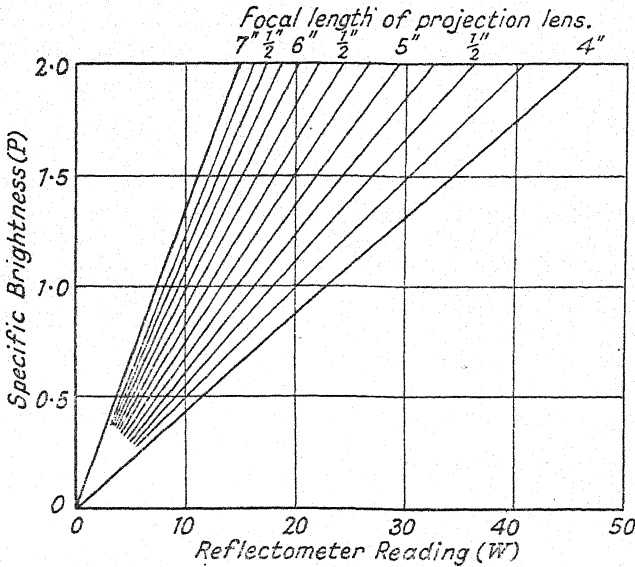


FIG. 105.

a standard projection lens, the screen was vertical, the projector raked down at an angle of 10° , and the measurements were taken looking upwards at an angle of 7° .

New screens tested show reflection effects within about 20° of the normal. The curves were plotted for an incident light of 100 foot-candles, when a perfect diffuser would have a brightness of 100 foot-lamberts, while that of a mirror would be about 7,000.

The lowest curve was that of an old screen, representing about the average amount of deterioration occurring in cinemas before retreatment is carried out.

American and German Recommendations

The Projection Practice Committee of the S.M.P.E. bases its recommendations on the incident light. They recommend that the average of nine readings shall lie between 10 and 20 foot-candles. They place 7-14 foot-lamberts in brackets after these figures, but it will be appreciated that the connection between incident light and screen luminance factor is very indefinite.

The German recommendations, on the other hand, are definitely based on screen luminance. They recommend a value, in the centre of the picture with shutter running, of 8.75 foot-lamberts (3 millistilb—specific brightness 1.75), and state that the values in practice should not be more than 20 per cent. under this. This reading is to be made from the seat nearest to the normal to the screen, but, as has already been stated, the ascertainment of this position presents considerable difficulty, and is not so practicable as the proposal to take the measurements from the operating box.

Appreciation of the polar curve of the screen is shown by the further stipulation that from no point in the auditorium shall the screen luminance be less than 4.4 foot-lamberts (1.5 millistilb—specific brightness 0.88) or more than 11.7 (4 millistilb—specific brightness 2.34). The method of measurement which they recommend consists of measurement of the incident light followed by determination of the luminance factor of the screen by means of small test surfaces. This is a much slower and more inaccurate method than taking direct and instantaneous readings with an instrument of the reflectometer type. It also suffers from the serious defect that it is not capable of measuring the apparent colour of the screen.

Measurement of Screen Coloration

Measurement of Energy Bands

The first method tried in the Morganite Laboratories involved the use of a spectrophotometer, which enabled the energy at each wavelength to be plotted. The method was laborious and could be attempted only in a laboratory. Even then, however, it was found impossible to predict from the graph what the visual effect would be. The spectrum of the light from a projection arc is a continuous one on which lines are superimposed. It was thought at first that the failure was due to the great difficulty of measuring the energy on a particular line, and also of keeping the light constant during the hour or so required for a set of measurements.

A method was therefore developed of splitting the visible spectrum into eight bands by means of filters and integrating the energy in each band. In this manner it was possible to obtain the complete set of eight readings in about a quarter of a second, thus eliminating errors

due to variation in the light output of the arc. Once again it proved impossible to predict the visual effect of changes in the colour of the light.

Success was eventually achieved by reducing the number of filters to three bands only. If the bands of these three filters correspond to those used in colour film process, accurate predictions are possible. Early work was carried out with Ilford filters 205, 304, and 404, but latterly it was found that the red filter 204 gave slightly better results, and all Morganite reflectometers are now fitted with 204.

Two methods of expressing results are in use. Prediction of visual effect can obviously be based only on comparison of the light under review with a standard. Heys-Hallett was therefore forced to adopt a standard at the commencement of his work, and the standard selected might be described as an average based on the projection performance of high-intensity projection arcs.

“Equal Green” Method

This method of comparing two colours depends on eliminating one of the filter readings—always the green—by expressing the set of readings as a percentage of the green reading. Even then the set of readings for a cinema would be quite meaningless to everyone, and recourse is therefore had to the solution worked out for screen luminance—that is, all readings are expressed arbitrarily as a function of a standard, and termed “specific colour.”

TABLE 37.—“SPECIFIC COLOUR”

<i>Colour.</i>	<i>Cinema Readings.</i>		<i>Standard Colour— 205 404 304</i>	<i>Specific Colour.</i>
	<i>Actual.</i>	<i>Expressed as per Cent. of Green.</i>		
Red	6.3	59	45	1.31
Green	10.7	100	100	1.0
Blue	4.0	37.5	50	0.75

An example is given in Table 37, showing readings of a cinema which has a light which is 31 per cent. high in red and 25 per cent. deficient in blue. It is possible with a little practice to get some idea of what the visual effect will be, but as two specific colours are involved it is not easy. This example is one of the simpler ones, but sometimes both blue and red specific colours exceed unity. A method of reducing the description to a single expression has therefore been evolved.

Dominant Hue.—Knowing the specific colours, calculate the percentage of the total represented by each, thus:

$$\begin{array}{r} \text{PR } 1.31 \\ \text{PG } 1.0 \\ \text{PB } 0.75 \\ \hline 3.06 \end{array}$$

therefore

$$\%R = \frac{1.31 \times 100}{3.06} = 42.8$$

$$\begin{array}{l} \%G = 32.7 \\ \%B = 24.5 \end{array}$$

Similar treatment of the standard colour (Pr. 1.0, Pg. 1.0, Pb. 1.0) obviously gives $33\frac{1}{3}$ for each.

These colours are then plotted on the wheel diagram (Fig. 106). Standard colour is represented by the point at the centre of the diagram, since if we plot $33\frac{1}{3}$ units towards green, turn 60° and plot $33\frac{1}{3}$ units towards blue, followed by $33\frac{1}{3}$ units in the direction of red, we return to the point from which we started. The other set is then plotted in a similar manner, and the triangle fails to close, indicating a colour difference of 15.6 per cent. orange, the visual effect of which is easily pictured in the mind.

When using this diagram to compare two non-standard lights, Heys-Hallett proceeds as follows:

"First multiply each colour reading of one light by the requisite factor to bring it to $33\frac{1}{3}$ and thus make it the centre of the diagram.

"Now multiply each colour reading of the other light by the same factor as was used for the same colour of the first light. Add up the three results and multiply each by $\frac{100}{\text{total}}$. The results thus obtained

will add up to 100, and are the percentage readings required for the colour wheel. Note that in this case it is not necessary first to calculate the specific colours."

This method is not very accurate if the lights are far "off-white," but is sufficiently close for the purposes under review.

Heys-Hallett uses an arbitrary circular diagram which departs radically from present-day methods of colour specification.

Use of Colour Circle.—The colour of projection arcs varies for a number of reasons. The shaded area in Fig. 107 shows these variations for a representative modern high-intensity mirror arc designed to operate round about 50 amperes. The lamp was tested over a range of 10 amperes with several grades of carbon of different makes. The lamp was properly handled throughout the test, and the shaded area therefore represents the envelope which will be obtained when the lamp is run strictly in accordance with the maker's intentions. Cases of under- or over-loading will, however, occur in practice.

The difference between high intensity and low intensity is most marked. The point A in the diagram indicates the average of low-intensity mirror arcs when correctly run at approximately full rating. Reduced loading will, of course, make the light even redder.

The effect of unusual design is shown by point C, which indicates the difference between the Stelmar arc and another lamp, represented

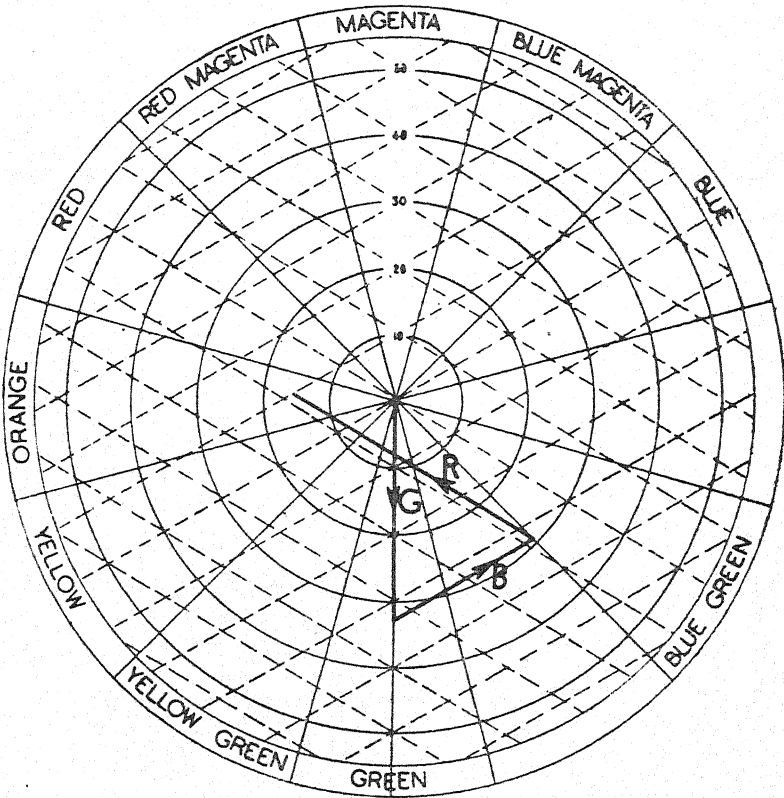


FIG. 106.—Method of plotting predominant hues on colour circle (C. G. Heys-Hallett).

by the shaded area, while B is the point for an A.C. high-intensity projection arc.

Some attempts have been made to use metal mirrors instead of glass, and point F, comparing a rhodium mirror with a glass one, is therefore of interest.

Screens have a powerful influence, as illustrated by point H, which shows the change in colour during the life of the screen. Point K is for a beaded screen, while all other types of screen tested lie, when new,

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between 2.5 per cent. orange and 3.5 per cent. blue-green. Point E shows the change effected by re-treating the screen in a particular cinema.

It is not safe, with a diagram of this type, to attempt to guess the result of combinations. For example, a blue-green projection light, represented by the point L, would be altered to the points L and F if the glass mirror were replaced by the rhodium mirror F.

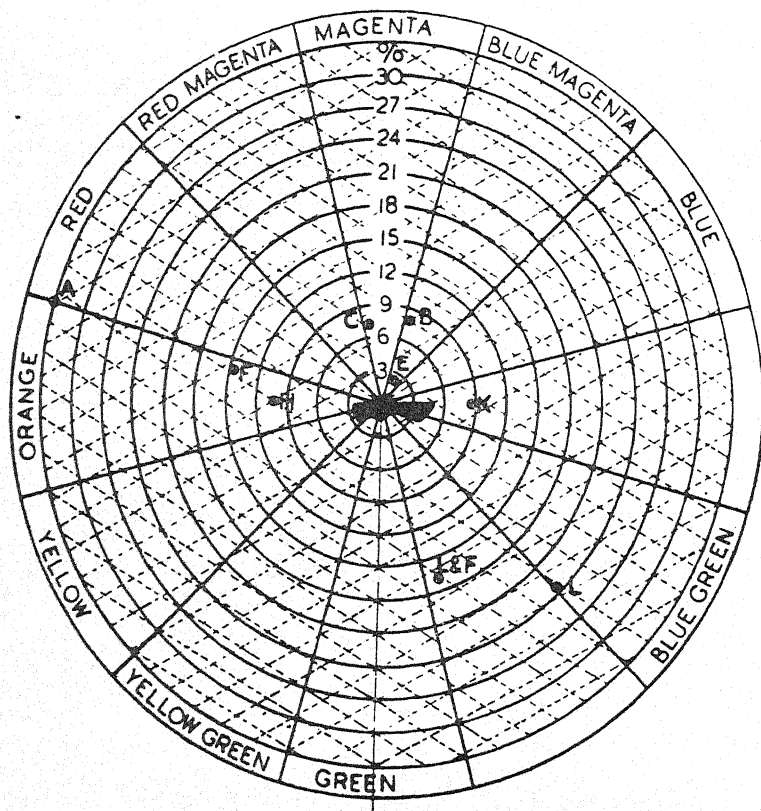


FIG. 107.—Examples of readings plotted on colour circle (C. G. Heys-Hallett).

Conclusion

The effect on the contrast of the picture due to stray light reaching the screen from directions other than the projection lens is important, and it is therefore necessary to draw up standards to cover this point also.

According to Heys-Hallett a satisfactory standard code must cover the following points, which have been shown to be of importance.

- (a) Maximum and minimum average brightness of the screen as viewed from the operating box.
- (b) Maximum difference in brightness as viewed from any two seats in the auditorium.
- (c) Maximum deviation from standard apparent colour of the screen.
- (d) Maximum screen brightness due to light reaching the screen from directions other than that of the projection lens, expressed as a percentage of the actual screen brightness derived from the projection light alone.

We might at this point discuss the relation between the lighting of the auditorium and its colour relationship to the projected film. It is a fact that the conditions for appreciation of delicate colour contrasts are at their worst with the present projection system, since the frame of the picture is a large area of intense gloom—more or less black. It is certain that if we could surround the picture with a frame of neutral white of lower lightness than the white of the picture (neutral grey, in fact), the pale, desaturated tones of the picture would immediately take upon themselves a new value.¹ When we are a long distance from the screen we might compare the effect to looking out upon an intensely lit exterior from the depths of a cave. Under these conditions it is quite impossible to appreciate the colour of a delicate sky, for example. The theatre manager would probably reject this project if it were put before him, but it remains fairly sure that the quality of the colour picture would be vastly improved by a surround of pale grey light, fitting it quite closely, like a mount or frame. The practical difficulties are slight and as an experiment it would be well worth trying.

The present habit of throwing a flood of red on to the screen, dimming this, and then fading into the picture, and perhaps simultaneously withdrawing a curtain, will have to be given up if a colour picture is about to be projected. The after-image of the approximate complementary hue would seriously affect the colour balance of the title for an appreciable time. For the same reason it is important that the audience should not be subjected to any colour fatigue just before the picture is shown.

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¹ See "Illuminating the Screen Surround," *Kine Weekly* (Dec. 1, 1949), Vol. 394, No. 2222, p. 37. This reference describes the "Kolorig" French system.

8. THE PSYCHICAL AND PHYSICAL RESPONSE TO RADIANT STIMULUS

The Physical Stimulus

The physical stimulus is *Radiant Energy* travelling through space in the form of electromagnetic waves of various lengths. The wavelength limits of radiant energy capable of evoking visual sensation extend roughly from 700 $M\mu$ to 400 $M\mu$ (millimicrons).

The Psychical and Physical Response to the Stimulus

There are two approaches to the general subject of light and colour:

Physical. *Objective.*

Psychical (or Psychological). *Subjective.*

Specifications of physical stimuli in terms of equality, or difference, of *sensations* experienced by human observers are sometimes called "psychophysical measurements."

LIGHT

Radiant energy capable of stimulating the eye and causing the sensation of vision. Often extended to radiation near to the visible region of the spectrum, e.g., ultra-violet light, infra-red light. Light actually entering the eye may be more specifically referred to as the visual stimulus (1).

COLOUR

(a) *That characteristic of the visual sensation which enables the eye to distinguish differences in its quality, such as may be caused by differences in the spectral distribution of the light rather than by differences in spatial distribution or fluctuations with time.*

(b) *As (a) but applied directly to the stimulus, or the source (primary or secondary) giving rise to the sensation. For brevity the stimulus is often referred to as the colour..*

(c) *That property of an object or stimulus, or quality of a visual sensation, distinguished by its appearance of redness, greenness, etc., in contradistinction to achromatic colour.*

The characteristics of light which constitute colour can be specified in:

Objective Terms

- (1) The appropriate photometric quantity (Luminance, Luminous flux).
- (2) Dominant wavelength.
- (3) Purity.

These characteristics of *light* correspond to the following three attributes of *visual sensation*, specified in:

Subjective Terms

- (1) Luminosity (and applied to sensations and secondary sources only, Lightness).
- (2) Hue.
- (3) Saturation.

LUMINOSITY, a psychological term, can be defined as *that attribute with respect to which a colour may be rated as equivalent to some member of a series of greys of which black and white are the terminal members.*

All colours possess luminosity and fall naturally into two classes:

1. Those which possess no other attribute.
2. Those which possess other attributes in addition to luminosity.

Colours which possess no attributes other than luminosity are called *greys*.

Luminosity is the attribute of colour sensation which is most distinctly quantitative. This is a consequence of the fact that it is the attribute which varies most markedly when the magnitude of the stimulus is changed. The terms *high luminosity*, *medium luminosity*, and *low luminosity* are appropriate for the description of the luminosity of colour sensations.

The objective term LUMINANCE corresponds with luminosity. Light is rarely temporally constant or spatially uniform throughout the entire field of vision. Nevertheless, in accordance with the O.S.A. definition of colour, the light from each portion of the field which is uniform and constant during an appreciable time has a definite colour. Those varieties of light which are occasionally called "colourless" have a colour according to the usage recommended by the O.S.A. Colorimetry Committee, the purity of the colour of neutral, or "white," light being zero and the dominant wavelength indeterminate.

HUE, a psychological term, is *that attribute of certain visual sensations by which we distinguish red, green, blue, yellow, purple, etc., from one another and by which the eye distinguishes different parts of the spectrum.*

The corresponding objective term is DOMINANT WAVELENGTH. The dominant wavelength of a sample colour is the wavelength of spectrally homogeneous radiant energy which would have to be mixed with an appropriate amount of achromatic, or "white," light in order to match the *chromaticity*. The term CHROMATICITY refers to the characteristics specified by dominant wavelength and purity. Any psychophysical specification of colour which embodies the same information as dominant wavelength and purity, but not photometric magnitude, is a specification of chromaticity.

SATURATION, a psychological term, has been defined by the Colour Group Committee of the Physical Society as *that attribute of visual sensations which permits a judgment to be made of the proportion of colourfulness in the total sensation. Sensations of the same hue and luminosity can be arranged in a series of increasing saturation ranging from grey to that member of the series in which the hue appears most marked* (2).

As is the case with luminosity, saturation also has a quantitative, as well as a qualitative, character, and the use of the terms *high saturation*, *medium saturation*, and *low saturation*, are suitable for the description of the saturation of colour sensations. When, in a stimulus consisting of a combination of chromatic and achromatic light, the propor-

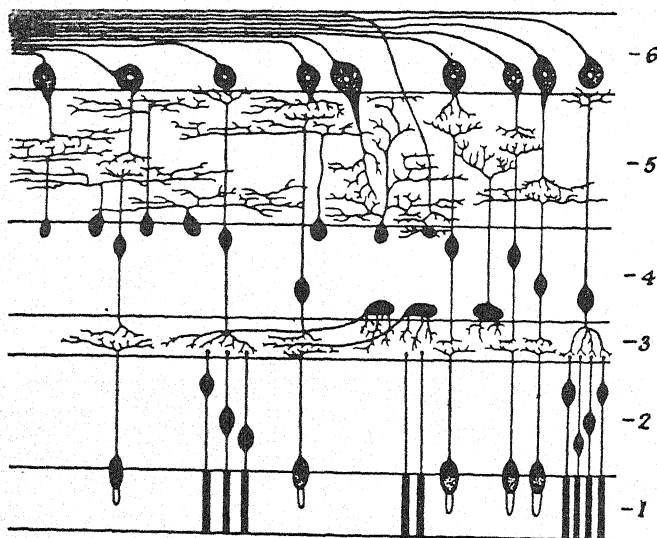


FIG. 108.

tion of the chromatic component is increased, the saturation of the colour sensation varies correspondingly. In the sense that it varies in the same manner as the proportion of the chromatic component in the stimulus, saturation may be considered a quantitative attribute of colour sensation.

The corresponding objective term is PURITY. Purity is an expression of the proportion of the spectrally pure component in the mixture matching the chromaticity of the sample.

The Eye (Condensed Description)

The eye is much like a camera, in which the *cornea* and *crystalline lens* represent the lens-system, the *iris* the diaphragm, and the *retina* the sensitive plate.

THE THEORETICAL BASIS

The optical system of the eye is not achromatic (namely, the focal length is different for different wavelengths).

The retina as a whole consists of six distinct layers (Fig. 108):

- (1) The rod and cone layer, lying below an outer limiting membrane.
- (2) The outer nuclear layer, containing the nuclei of the rod and cone cells.
- (3) The outer molecular layer, where the rod and cone cells, which together form the first relay of the optic circuit, terminate and make contact with the thread-like processes of the bipolar cells, which form the second layer of the circuit.
- (4) The inner nuclear layer, containing the nuclei of the *bipolar* cells.
- (5) The inner molecular layer, where the bipolar cells terminate and make contact with the processes of the *ganglion* cells, the third relay of the circuit.
- (6) The ganglion cell layer, which contains also the nerve fibres running to the optic nerve and thence to the brain.

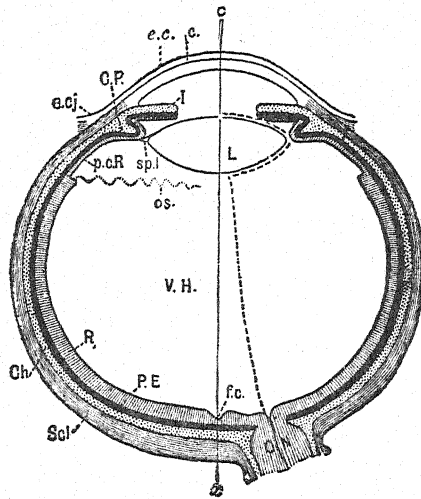


FIG. 109.

Fig. 109 represents a diagrammatic section of the eye. R is the retina; L is the lens, containing a liquid, the refractive index of which is 1.4371; VH is the *vitreous humour*, consisting of a jelly-like material containing chiefly water, the refractive index being 1.3365; ON is the optic nerve connected with the brain (contains about one million "insulated" nerve cables—probably one for each cone in the *fovea centralis*); OX is the optical axis of the lens; FC is the *fovea centralis*, a small depression in the *macula lutea*, or *yellow spot*.

The Retina.—The average thickness of the retina is 15 mm. There are several layers of cells and neurones, through which the light has to travel before it reaches the sensitive layer of light reception known as the *rods* and *cones*.

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Rods and Cones.—There are 6,500,000 cones and some 120,000,000 rods (Fig. 110).

The cones are concentrated in the fovea, which has no rods. The proportion of rods steadily increases towards the periphery until the receptors are all rods. Each cone is believed to be connected to one

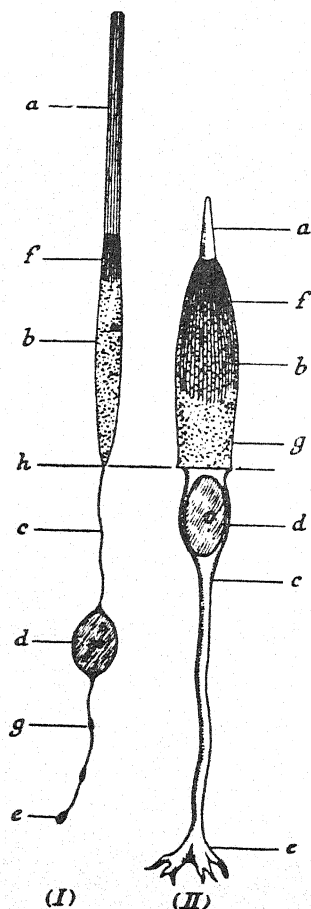
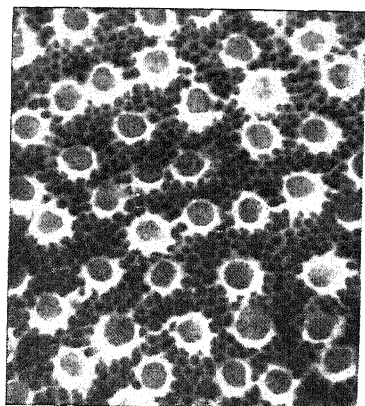


FIG. 110.

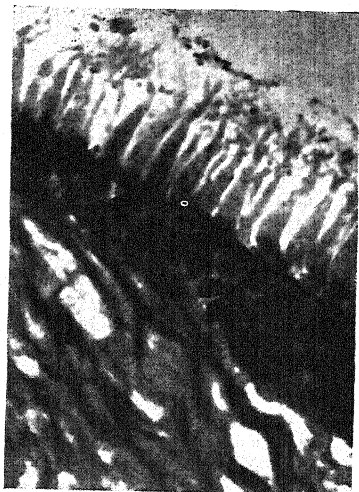
nerve fibre, whereas 60-100 rods converge on a single fibre. The rods contain a highly light-sensitive substance, visual purple.

The cones also exude a similar light-sensitive compound.

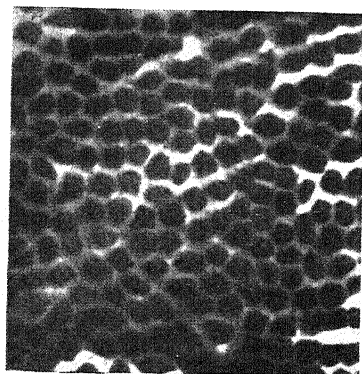
Rods.—Each rod has two distinct parts, the outer and lower limbs. The outer limb is a cylinder about $\frac{3}{100}$ mm. in length and $\frac{2}{1000}$ mm. in diameter. It is transparent and doubly refractive, and is probably made up of a very large number of discs of about $\frac{6}{10000}$ mm. in



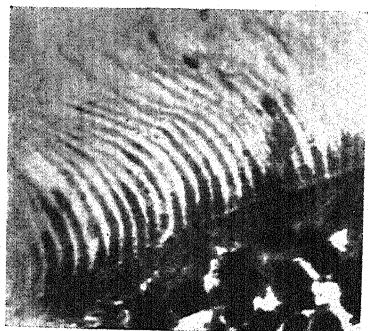
Transverse section through the rods and cones of the retina.



Section of the outer layer of the retina near to the fovea.



Transverse section through the cones of the retina at the fovea.



Section of the retinal cones at the fovea.

FIG. 111.—Photomicrographs of the Retina (Fincham, *Phot. Jour.*, 76, 268, 1936).



thickness cemented together. The cylinder is sensitive to light, swelling up under its action, and shrinking again under prolonged exposure to light. The inner limb is truncated and tapers to a delicate thread, which eventually connects with the optic nerve.

The rods, owing to their visual purple, are far more sensitive to small amounts of light than the cones. Rod vision is colourless. The visual purple is decomposed by light and reformed in the dark, giving the rods adaptation power after being in the dark for half an hour. Rod vision is often referred to as *visual purple vision*, because in the cones there occurs something fundamentally different which originates colour perception. Rods are the receptors for night vision, and as they are not present at the fovea this is almost blind, so night pilots are taught to use the periphery of the retina for maximum perception in the dark. The maximum absorption of visual purple is at $502\text{ M}\mu$, and the dark-adapted luminosity curve has its maximum at $510\text{ M}\mu$. This shows fairly close agreement.

Cones.—As closely crowded as 13,000 per 0.1 sq. in. in the human fovea, the cones are each about 0.002 mm. diameter at the light-receiving end (the base) and 0.05 mm. long. The light-sensitive substance is probably secreted within and spreads over the surface. The products of the decomposition by light of the photochemical substance initiate nerve impulses which travel inwards to their "receiving end" in the brain. In spite of the incontrovertible evidence of triplicity in the phenomena of colour mixture, there is as yet no evidence for the existence of three kinds of cone adaptor, nor of three photosensitive substances in each cone, nor, alternatively, of three groups of cones each containing a different light-sensitive substance.

Dr. Wright says ("Survey of Modern Researches in Colour Vision, Institute of Ophthalmic Opticians," *The Refractionist*, 31, 1942, p. 53): "As a working hypothesis that is most in accord with current views we may assume that to produce a visual response the light has to pass inside a cone and react with light-sensitive material on its surface. In the centre of the cone we will also assume the existence of a reservoir of inactive photochemical substance for use in maintaining the supply of active substance on the surface. These suggestions are only tentative, but in the present state of our knowledge all we can attempt to do is to discover the most probable mechanism in the light of the information available."

Information concerning the light-sensitive substance or substances in the cones seems to be less than that known about the rods, but this is due to their presence in very minute quantities and in dilute form.

Electrical Impulses.—Professor E. D. Adrian in 1932 showed that single nerve fibres from certain receptors convey an electrical impulse which varies in frequency but remains constant in intensity for stimuli of

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various intensities (3). Professor R. Granit¹ of Sweden has developed a technique whereby, using micro-electrodes, threshold responses of single nerve fibres to various wavelengths have been measured. Retinæ of animals, consisting of rods only and charged with visual purple, gave a response against wavelength closely agreeing with the photosensitivity of visual purple, a curve known to be almost identical with the luminosity curve of the human dark-adapted eye. In order to isolate the cone response, experiments were carried out with the eye of the snake, which

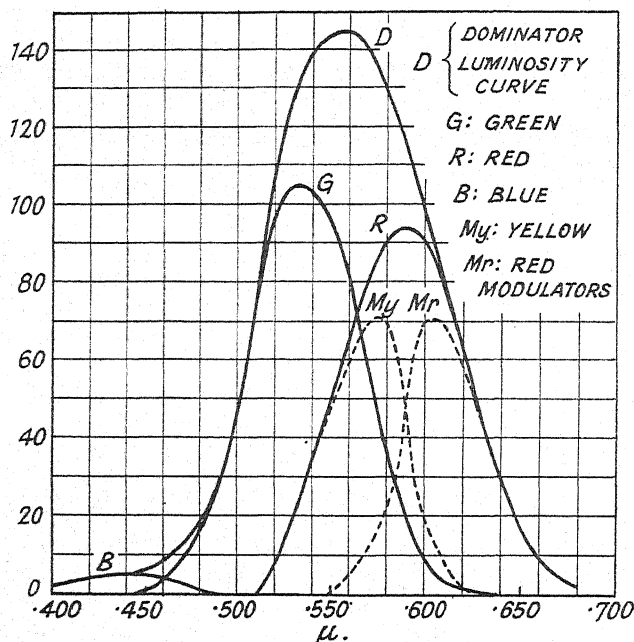


FIG. 112.—Synthesis of human photopic luminosity curve (*D*) as determined by Coblentz and Emerson (Bull. Bur. Stand. Wash. No. 303, 1917), on the basis of three fundamental sensation curves *R*, *G* and *B*. The *R*-curve indicated to be the sum of two modulators *M_y* and *M_r*. Equal energy spectrum (Granit. *Jour. Neurophysiol.* 8, 1945).

consists wholly of cones. A broad curve was obtained with a maximum at 560 $M\mu$, and this curve Granit calls the *dominator* (Fig. 112). Optic nerve fibre units being convergence units of a number of receptors, it is probable that several receptors combine to yield this *dominator*. Occasionally much narrower curves are obtained and the striking fact emerges that these narrow curves are confined to three preferential regions of the spectrum. These narrower curves Granit calls *modulator* curves. A characteristic modulator has a maximum at 600 $M\mu$. In the frog he found a yellow modulator with a maximum at 580 $M\mu$.

¹ Professor Ragnar Granit of the Neurophysical Department of the Caroline Institute, Stockholm.

Green modulators are found in all eyes with maxima between 520 $M\mu$ and 540 $M\mu$. Blue modulators around 460 $M\mu$ occur in the guinea-pig, which possesses an exclusively rod eye. Granit then asked himself whether the *dominator* could be regarded as being formed by grouped modulators. Measurements by Dr. W. D. Wright of the luminosity curve derived from the retinal image of a very small point of light had exhibited a hump (foveal stimulation) in the red in the region 600 $M\mu$. Granit obtained a similar hump in the cat's dominator curve. By adapting the dark-adapted eye of the animal to narrow spectral regions, modulator curves were obtained which, when averaged, were found to sum to the animal's photopic dominator. Granit remarks: "In the light of these experiments it seems permissible to maintain that the dominator is a composite curve consisting of modulators. . . . Why have modulators never been found in the human eye with sensory methods? The main reason would seem to be that the analytical unit field contains too many elements, perhaps up to a hundred thousand nerve fibres. . . . It should be emphasized that these electrophysiological experiments have not provided any evidence for the existence of three fundamental response curves. From the physiological point of view, colour vision must be understood in terms of modulators and dominators."

Granit concludes that the standard photopic and scotopic luminosity curves of the human eye represent typical dominators, both of them being responsible for white sensation, or luminosity. The colour aspect is carried by the modulators as a kind of "local sign." Accordingly, Granit considers white as a separate sensation. In support he notes that "The distribution of saturation in the spectrum is very characteristic. The ends are saturated and at the same time dark, extreme red and extreme blue being examples of such dark and saturated colours. On the dominator-modulator concept this is explained by the fact that at the ends of the spectrum the dominator values are very low, so that the modulators in these regions are responsible for the greater part of the sensory experience. Again, in the yellow region the large contribution from the dominator makes the spectrum appear relatively white and the colour unsaturated."

Adaptation

If the eye has been exposed to intense radiation it is said to be *light-adapted*. If the eye has been free from radiation for a considerable period it is *dark-adapted*. The sensitivity depends upon the relative decomposition of the light-sensitive compounds in the retina. Reduced concentration initiates a proportionately weaker sensation.

Response and Circumstance

The colour concepts are ultimately psychological, and indeed wholly subjective; but the usual original stimulus is radiant energy.

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The colour sensation is strictly determined not solely by the radiant energy but also by the circumstances or conditions under which the radiant energy is incident upon the retina. These conditions include: (1) the size of the field; (2) the state of adaptation resulting from previous exposure as well as present stimulation; (3) the type of the individual observer's visual system; (4) the particular part of the retina receiving the energy; (5) the simultaneous stimulation of other parts of the retina.

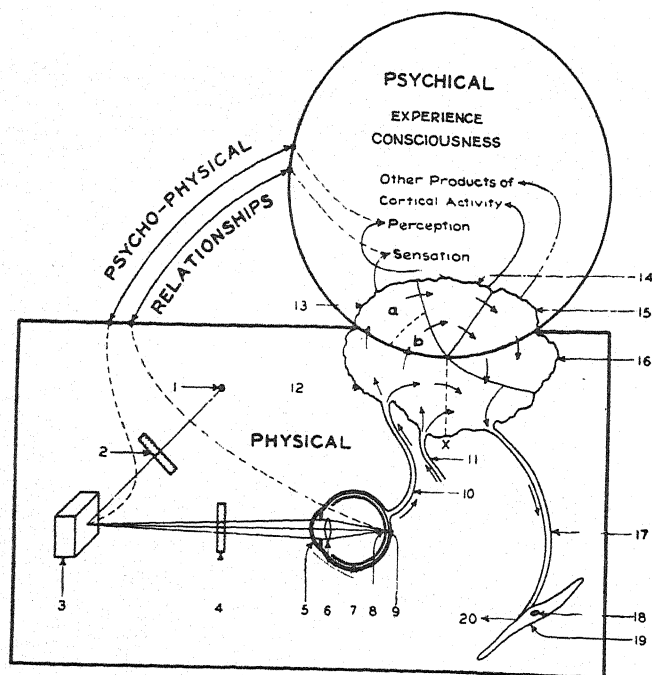


FIG. 113.—Psychophysical Relationships. (By courtesy of the Colorimetry Committee of the Optical Society of America.)

Psycho-physical Aspects

Before giving some tables of the reactions of the eye to radiation, reference should be made to the psycho-physical phenomena. We know that there is a long and infinitely complicated process of transformation from the physical stimulus to the mental process.

This *psycho-physical* process is well set forth in "The Concept of Color," Chapter II of the report of the Committee on Colorimetry of the Optical Society of America. Fig. 113, from this report, represents the categories of visual psychophysics.

KEY TO FIG. 113

1. The radiator, or source of light.
2. Absorption occurring between source and object.
3. The object upon which the radiation is incident.
4. Possible materials between object and eye, modifying intensity and quality, including losses by scattering and reflection.
- 5 and 6. Radiant energy enters the eye, being refracted by the various elements and forming an image on—
7. The retina, at the point—
8. Image plane, where the radiant energy falling upon the rods and cones gives rise to a photochemical or photoelectrical reaction.
9. This excitation leads to nerve impulses which are propagated through the nerve fibres and synapses connecting these elements with the fibres of the optic nerve.
10. The optic nerve.
- 11 and 12. Subcortical portion of the cerebrum. Synaptic processes controlling impulses flowing into the cortex.
13. Sensory projection area of the cortex.
- 13-16. Cortical areas of the cerebrum.
- 14-15. Association areas.
16. Motor projection areas.
17. Outgoing or *efferent* nerve impulses activating the muscles and motor nerves.
18. "End-plate" processes.
19. Muscle fibres.
20. Muscular reactions finally induced.

"Everything which occurs from 1 to 8 is of a purely physical or objective nature. The characteristics of each link in the chain of events can be measured and specified completely in physical terms. Moreover, the interrelations between these various phenomena can be expressed as purely physical functions. We can, for instance, express precisely the characteristics of the image, 8, formed on the retina in terms of purely physical units. These characteristics, of course, include shape, size, and position of the retinal image, as well as the intensity and quality of the radiant energy at all points in the image."

It is proposed in the same report that the "chain of events leading up to the formation of and including the image on the retina" should be called the *stimulus process*, the immediate stimulus being the *retinal image*. "The *response process* begins in or around the receptor cells, with the effect which occurs as a result of the absorption of the radiant energy of which the retinal image is composed, and continues inward along the afferent nerve fibres to the central nervous system and thence outward along the efferent nerve fibres terminating with the epithelial (that is, either muscular or glandular) reaction and its effect on the organism or its environment. This entire chain of physiological events, 9 to 20, inclusive, is called the *physical response arc*. The term physical is applied to the events from 9 to 20, as well as those from 1 to 8, because this entire chain of events, 1 to 20, appears to be causally connected and governed by objectively discoverable principles. Only

the events from 1 to 8 can be investigated by the techniques employed in the specialized science of physics. The methods of physiology which are more appropriate to the investigation of the phenomena from 9 to 20 are adaptations of the methods of physics and chemistry to the study of living organisms, and the science of physiology can be grouped with the physical sciences in the same sense that chemistry is a physical science. In the same sense the physiological and chemical phenomena, 9 to 20, which are not proper subject matter for the specialized science of physics, are nevertheless physical in a generalized sense. In this sense the phrase *physical response arc* is used to emphasize the connections between the events 1 to 20, in contrast with the essential distinction of all these concepts from psychical or subjective concepts. The physical response arc is divided quite naturally into two parts, namely, the

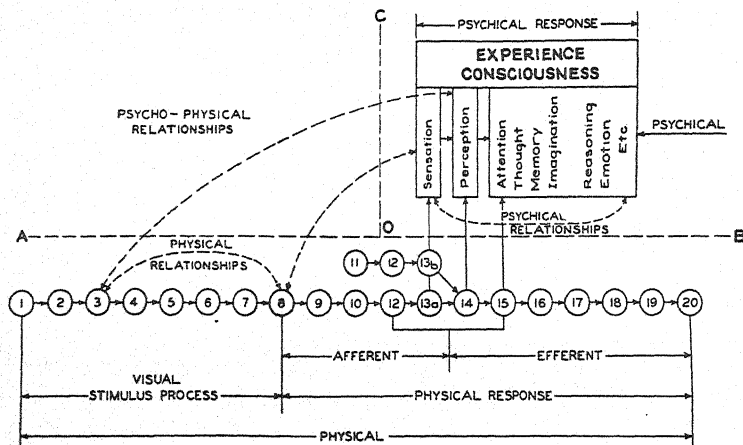


FIG. 114.

(By courtesy of the Colorimetry Committee of the Optical Society of America.)

afferent arc including conduction into the cerebrum, and the efferent arc, including conduction from the cerebrum along the efferent nerve fibres."

The information presented pictorially in Fig. 113 is represented diagrammatically in Fig. 114. Everything below the horizontal line AB belongs properly in the general physical category. The *visual stimulus* extends from 1 to 8, the *physical response* from 8 to 20, subdivided into afferent and efferent response arcs. The one ends and the other begins at some point between 12 and 15. The psychical area lies above the line AB and to the right of the vertical line OC. The psychical aspect of the response to physical stimuli is experience and consciousness, comprised of more specific psychical activities such as sensation, perception, memory, etc. The diagram also indicates by its structure that nervous activity in the sensory projection areas of the cortex,

13a and 13b, gives rise to sensation. The propagation of nerve impulses from the sensory areas of the cortex into the adjacent associative area, 14, of the cortex and the interaction there with other possible cortical activities gives rise to perception.

Summarizing, the report notes three general classes: physical, psychophysical, and psychical. The *psychical response* is the subjective aspect of the impulses in the sensory projection areas and in the associational areas of the cortex.

"Psychological relationships include correlations between subjective aspects of the observer's response and are established by application of the criterion that the relationship must be evident introspectively or perceptually to the observer. Individual differences are accepted and consequently, it is not to be expected that all observers will report the same psychological relationships. Disagreement is not always an indication of incorrectness of psychological concepts or relationships. Under some conditions group agreement may be expected."

No doubt this approach to the treatment of the totality of the phenomena of the experience of vision may be challenged on one score or another by physicists, physiologists and psychologists in turn, but to the writer in any case, it appeals as a philosophically sound conception, and as a fruitful thought pattern.

One of the founders of modern psychophysical methods was Weber. He noted that "a stimulus must attain a certain intensity in order to excite a sensation, and that stimuli of greater intensity excite stronger sensations." Therefore there is a quantitative relationship between the stimulus and the sensation. The minimum effectual intensity of stimulus is called the *general threshold* or the *general liminal value*. Thus a light of low intensity may awaken only a grey sensation when at a higher intensity it may excite a sensation of *hue*.

The intensity has to be increased by a definite amount before a difference in the amount of the sensation becomes perceptible. This is the *differential threshold* or the *liminal discrimination value*.

Equal increases of physical intensity do not give equal increases of sensation.

Weber stated his conclusions in the form of a law:

The just appreciable increase of stimulus bears a constant ratio to the original stimulus—i.e., two stimuli, in order to be discriminated, must be in a constant ratio which is independent of the absolute magnitudes of the stimuli.

Fechner went further and expressed sensations in quantitative terms. Fechner stated that just noticeable differences of sensation contain an equal number of sensation units. The sensation, he says, *varies as the logarithm of the stimulus—i.e., the sensation changes in arithmetical proportion as the stimulus increases in geometrical proportion.*

Stated algebraically: If E is the measure of a sensation and δE the

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just appreciable difference, S the measure of the stimulus, and δS a small increment, then

$$\delta E = C \frac{\delta S}{S} \text{ (Weber's Law),}$$

where C is a constant; therefore, on the questionable assumption that it is permissible to integrate small finite quantities (δE), etc.,

$$E = C \int \frac{\delta S}{S}$$

$$= C \log. S + C' \text{ (Fechner's Law),}$$

where C' is another constant.

Weber's law does not hold for very low or very high intensities.

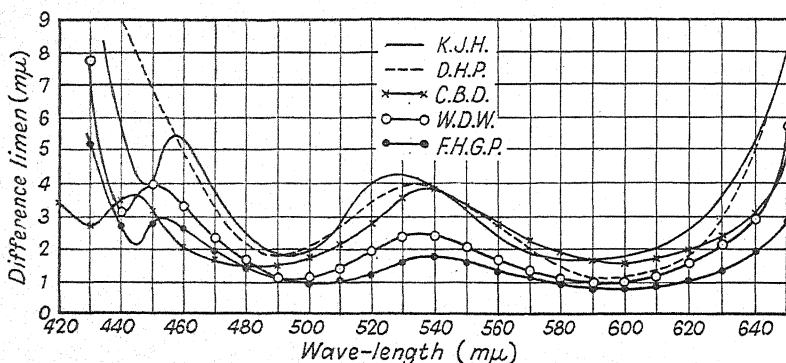


FIG. 116.—Hue-discrimination curves for five normal observers (W. D. Wright).

The principal psychological factors of vision are:

1. **Predisposition to associate certain hue characteristics with objects regardless of local radiation conditions or limitations.** For example, lips are thought to be still red, although they may appear quite *black* by mercury vapour light, as if the lips had an attribute of hue in themselves. But the redness is, we know, not an attribute of the lips, but of our sensation.
2. **Relativity of judgment.** The black printed letters of a newspaper may reflect more light (Hering) illuminated by sunlight than the white paper on which they are printed when illuminated by artificial light. Therefore, what is called black under one circumstance may be perceived as white under another.
3. **Hue.** Psychological analysis indicates that there are four ideas of hue: red, yellow, green, blue. (These form a closed series via the purples.)
4. **Luminosity.**
5. **Saturation.**

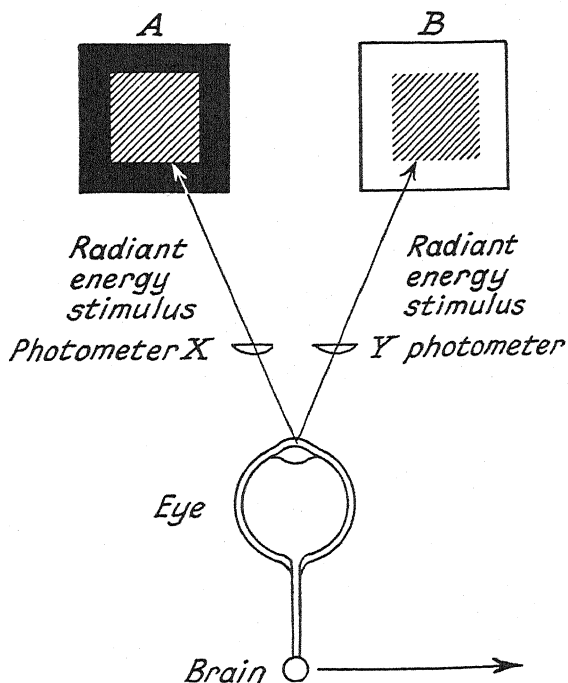


FIG. 115.—Luminance and lightness.

The difference between objective and subjective measures of the *quantity* of light.

The light reflected from A is identical in quantity to the light reflected from B.

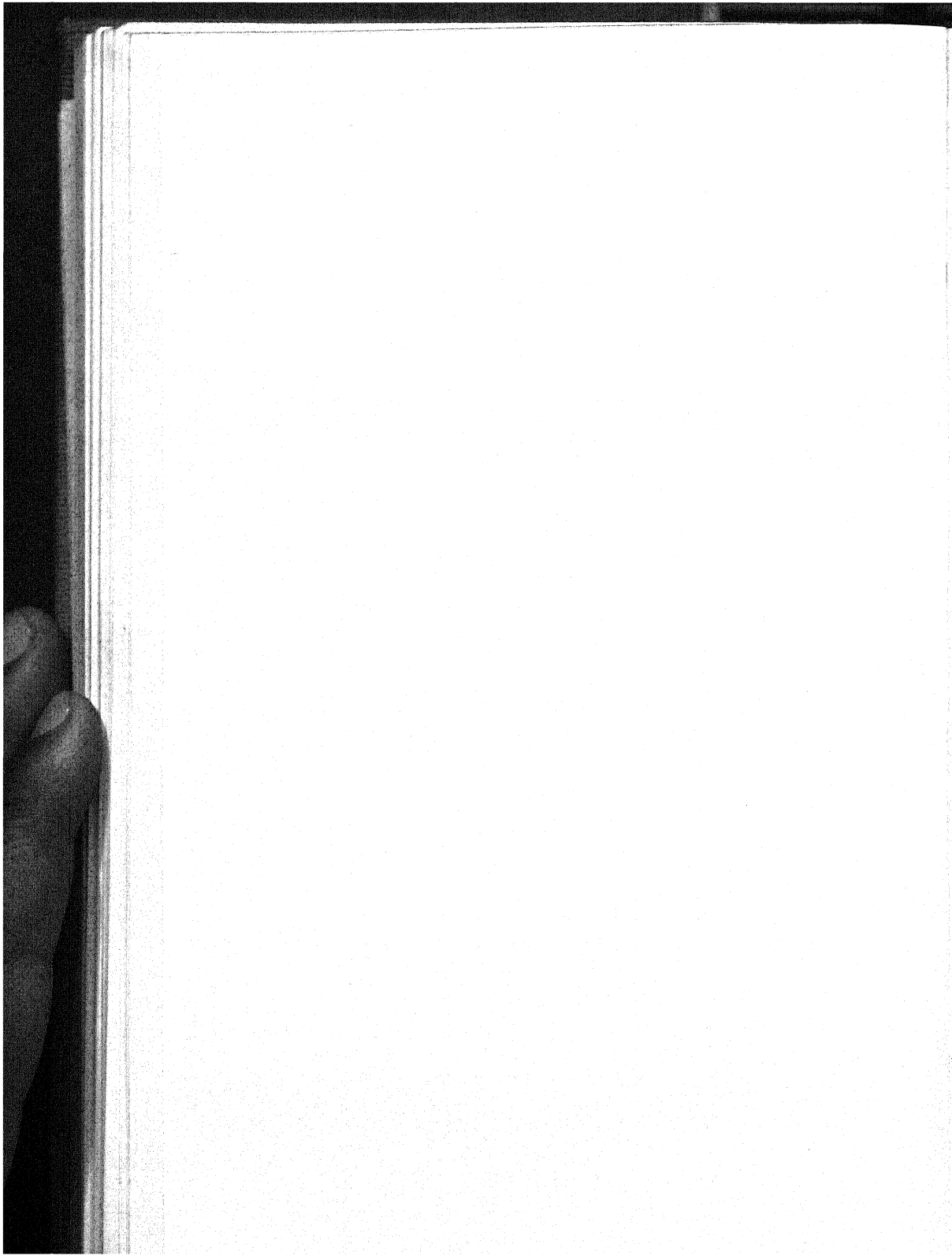
Photometer X gives same reading as photometer Y. This is an *objective* measurement. The word used for what has been thus measured is **LUMINANCE**. This is a psychophysical term, since it hypothesizes a measurable physical cause in its relation to the reaction of a percipient.

A *appears* lighter than B.

This is a *subjective* judgment or measure. The word used for what has been thus measured is **LIGHTNESS**. This is a psychological term, since it is descriptive of perception.

Clearly **LUMINANCE** can be related to an absolute measure of quantity based upon the visual efficiency of radiant energy.

On the other hand, **LIGHTNESS** is a relative matter subject to innumerable conditions, in the main physiological and psychological. Hence the eye is not a reliable photometer capable of absolute determination of the quantity of light. It is nevertheless capable of considerable accuracy in differentiating magnitudes under carefully controlled conditions.



6. **Lightness.** That attribute of visual sensation by which one surface is judged to reflect a greater or smaller proportion of the incident light than another (Fig. 115).

Sensibility to Differences of Wavelength

Hue discrimination has been measured by many observers. A

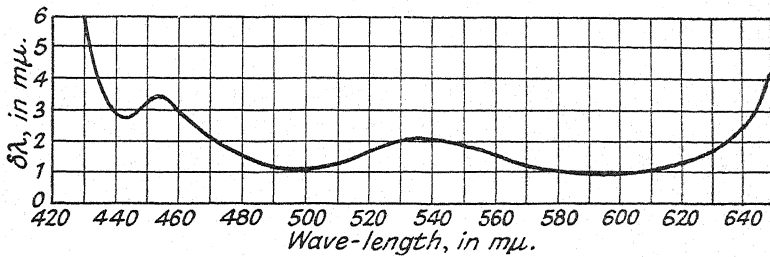


FIG. 116A.—Human hue discrimination according to Wright and Pitt (*Proc. Phys. Soc.* 46, 1934).

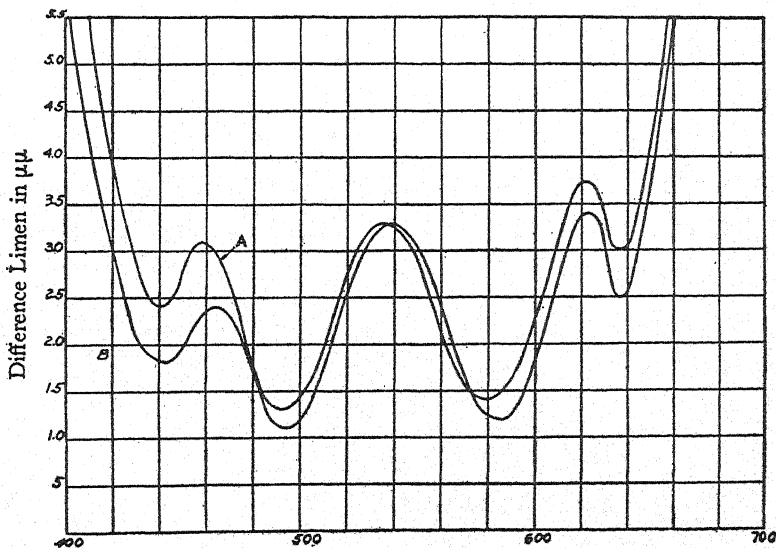


FIG. 117.—Minimum change of wavelength perceptible (L. A. Jones).

recent investigation by Wright and Pitt [5] shows the difference in wavelength necessary for discrimination of hue at adjacent wavelengths (see Fig. 116). Minima in the curve represent maxima of discrimination. Between 580 and 600 $M\mu$ wavelengths as little apart as 1 $M\mu$ can be distinguished. L. A. Jones [6] made a similar determination and derived

a hue scale of about 130 steps of just distinguishable difference in the spectrum (see Table 39). Note the high sensitivity in the yellow region (580-550 $M\mu$) and in the blue-green at 490 $M\mu$ (Fig. 117).

Sensitivity to Differences of Luminance

The retina is sensitive to differences of luminance over a very wide range, falling off at low and high intensities. König and Brodhun determined the least perceptible luminance increment for light of various hues and for white. As the intensity decreases, the sensibility diminishes more rapidly for rays of longer wavelength than for rays of shorter wavelength. (The unit of luminance in Table 40 is 0.004 millilamberts, which is approximately 0.004 foot-candles.)

The table shows the least luminance increment from about 0.00008 foot-candles to 4,000 foot-candles. From the table it will be seen that the range of luminance which gives the best discrimination is between 2,000 and 5,000 units—viz., between 8 and 20 foot-candles. The average luminous reflectance of screens in large theatres rarely exceeds 7 foot-candles (luminous reflectance of the screen measured during projection, inclusive of dark period).

TABLE 38 (BLANCHARD AND LOWRY)

<i>Luminance of Greater of Two just Noticeably Different Luminances.</i>		<i>Sensibility: Ratio of B to just Noticeable Difference of B.</i>	<i>Reciprocal of Sensibility.</i>
B (millilamberts)	log. B	B/ ΔB	$\Delta B/B$
0.000039	-4.41	1.9	0.521
0.000095	-4.02	2.7	0.372
0.000195	-3.71	3.3	0.302
0.00039	-3.41	3.9	0.254
0.00089	-3.05	4.1	0.246
0.0039	-2.41	7.6	0.131
0.0195	-1.71	16.7	0.060
0.039	-1.41	23.8	0.042
0.078	-1.11	31.2	0.032
0.39	-0.41	40.0	0.025
0.62	-0.21	37.0	0.027
0.98	-0.01	47.6	0.021
2.24	0.35	47.8	0.0209
6.61	0.82	59.2	0.0169
13.8	1.14	66.7	0.0150
25.1	1.40	73.0	0.0137
55.0	1.74	73.0	0.0137
97.7	1.99	72.5	0.0138
145.0	2.16	70.4	0.0142
224.0	2.35	69.0	0.0145

Sensibility to luminance differences (two-part field with unilluminated surround). (Values of $\Delta B/B$ for 5° field, by Blanchard given to three decimal places; values of $\Delta B/B$ for 3° field, by Lowry given to four decimal places.)

Other data by Blanchard and Lowry are given in Table 38. These data are given in the third column in the form of a ratio of the greater of two just noticeably different luminances to the difference between these luminances. The fourth column of the table gives the reciprocal of the sensibility, which has been called the difference fraction, the Fechner fraction and other names. Data of this kind are very much subject to the particular method of computation or representation employed—for example, the type of field used (7) (8).

TABLE 39.—MINIMUM CHANGE OF WAVELENGTH PERCEPTIBLE
(L. A. JONES)

Step No.	Wavelength (Mμ).	Difference (Mμ).	Step No.	Wavelength (Mμ).	Difference (Mμ).
1	700.0	—	36	586.4	1.1
2	678.0	22.0	37	585.3	1.1
3	665.0	13.0	38	584.0	1.3
4	659.0	6.0	39	582.7	1.3
5	654.0	5.0	40	581.5	1.2
6	649.5	4.5	41	580.3	1.2
7	646.0	3.5	42	579.1	1.2
8	642.8	3.2	43	577.9	1.2
9	640.2	2.6	44	576.5	1.4
10	637.8	2.4	45	575.2	1.3
11	635.5	2.3	46	573.7	1.5
12	633.1	2.4	47	571.7	2.0
13	630.0	3.1	48	570.1	1.8
14	626.5	3.5	49	568.4	1.7
15	623.0	3.5	50	566.6	1.8
16	620.0	3.0	51	564.8	1.8
17	617.3	2.7	52	563.0	1.8
18	614.9	2.4	53	561.1	1.9
19	612.5	2.4	54	558.6	2.5
20	610.2	2.3	55	557.0	2.6
21	608.0	2.2	56	554.4	2.6
22	606.0	2.0	57	551.8	2.6
23	604.1	1.9	58	549.1	2.7
24	602.3	1.8	59	546.1	3.0
25	600.6	1.6	60	543.0	3.1
26	599.0	1.6	61	539.8	3.2
27	597.4	1.6	62	536.5	3.4
28	595.9	1.5	63	533.2	3.3
29	594.5	1.4	64	530.1	3.1
30	593.1	1.4	65	527.1	3.0
31	591.8	1.3	66	524.2	2.9
32	590.5	1.3	67	521.4	2.8
33	589.5	1.0	68	519.1	2.3
34	588.5	1.0	69	516.8	2.3
35	587.5	1.0	70	514.6	2.2

TABLE 39 (continued)

Step No.	Wavelength (M μ).	Difference (M μ).	Step No.	Wavelength (M μ).	Difference (M μ).
71	512.6	2.0	100	470.5	2.4
72	510.6	2.0	101	468.2	2.3
73	508.0	1.6	102	465.8	2.4
74	507.0	1.0	103	463.6	2.2
75	505.4	1.6	104	461.2	2.4
76	504.0	1.4	105	458.7	2.5
77	502.6	1.4	106	456.5	2.2
78	501.3	1.3	107	454.4	2.3
79	500.0	1.3	108	452.1	2.3
80	498.7	1.3	109	450.0	2.1
81	497.4	1.3	110	448.0	2.0
82	496.1	1.3	111	446.0	2.0
83	494.8	1.3	112	444.2	1.8
84	493.7	1.1	113	442.5	1.7
85	492.6	1.1	114	440.8	1.7
86	491.5	1.1	115	439.0	1.8
87	490.0	1.1	116	437.2	1.8
88	489.4	1.0	117	435.3	1.9
89	488.2	1.2	118	433.3	2.0
90	487.0	1.2	119	431.3	2.0
91	485.8	1.2	120	429.3	2.1
92	484.5	1.3	121	427.0	2.2
93	483.2	1.3	122	424.8	3.2
94	481.7	1.5	123	422.3	2.3
95	480.0	1.7	124	419.7	2.8
96	478.2	1.8	125	416.7	3.0
97	476.5	1.7	126	413.8	2.9
98	475.0	1.5	127	410.4	3.4
99	472.9	2.1	128	405.8	4.6

WAVELENGTH LIMITS OF THE PRINCIPAL HUES
(in millimicrons)¹

	M μ		M μ
Red	700-620	Blue-green	515-500
Orange	620-590	Blue	500-463
Yellow	590-578	Ultramarine	463-445
Green	578-515	Violet	445-end

¹ NOTE.—Millimicron is expressed as M μ and is $\frac{1}{1000000}$ mm. This is equal to $\frac{1}{25400000}$ in. The wavelength of green light is, for example, about $\frac{5}{181000}$ in.

The Luminosity of Radiant Energy (Relative Spectral Luminance)

Variation in the wavelength of the stimulus produces besides variation in hue, a change in the sensation of luminosity. Thus the blue of the spectrum is less light than the yellow-green. Comparing the amounts of energy of each wavelength throughout the spectrum which will stimulate an equal sensation of luminosity, we can calculate the relative luminance of an equal energy spectrum. Plotted with relative luminance as ordinates and wavelengths as abscissæ, these data give a curve known as the Relative Spectral Luminance curve of the eye (Fig. 118). The

TABLE 39.—LEAST PERCEPTIBLE LUMINANCE CONTRAST (KÖNIG AND BRODHUN)

Wavelength (μ).	0.670 μ .	0.605 μ .	0.575 μ .	0.505 μ .	0.470 μ .	0.430 μ .	White.
Luminance ¹							
1,000,000							0.0358
500,000							0.0273
200,000							0.0267
100,000							0.0195
50,000							0.0173
20,000							0.0175
10,000							0.0176
5,000							0.0179
2,000							0.0181
1,000							0.0178
500							0.0192
200							0.0222
100							0.0245
50							0.0298
20							0.0324
10							0.0396
5							0.0477
2							0.0593
1							0.0939
0.5							0.123
0.2							
0.1							
0.05							
0.02							
0.01							
0.005							
0.002							
Threshold ..	0.060	0.0056	0.0029	0.00017	0.00012	0.00012	0.00072

¹ Unit=0.004 millilamberts.

The unit of luminance of a perfect diffuser is the emission of 1 *lumen* (1 candle-power=4 π lumens) per unit area. A *lambert* is 1 lumen per sq. cm., while a *foot-lambert* is 1 lumen per sq. ft. Therefore 1 millilambert=0.93 foot-lambert.

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luminance level at which observations are made causes that part of the spectrum which normally appears luminous to move towards the short-wave region if the intensity of the light forming the spectrum is much reduced. This is known as the Purkinje phenomenon (discovered by Purkinje, 1825). In light of very low intensity the blues appear considerably lighter than the reds.

Gibson and Tyndall [9] of the Bureau of Standards, U.S.A., determined a Relative Spectral Luminance curve for the "standard" eye the values of which were adopted by the International Commission on Illumination in 1924. Table 41 gives the values.

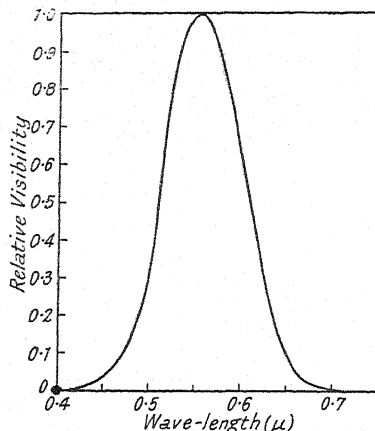


FIG. 119.—Relative Spectral Luminance for the standard eye (Gibson and Tyndall).

TABLE 41.—RELATIVE SPECTRAL LUMINANCE (GIBSON AND TYNDALL)¹

Wavelength in Mμ.	Visibility.	Wavelength in Mμ.	Visibility.
760	0.00006	570	0.952
750	0.00012	560	0.995
740	0.00025	550	0.995
730	0.00052	540	0.954
720	0.00105	530	0.862
710	0.0021	520	0.710
700	0.0041	510	0.503
690	0.0082	500	0.323
680	0.017	490	0.208
670	0.032	480	0.139
660	0.061	470	0.091
650	0.107	460	0.060
640	0.175	450	0.038
630	0.265	440	0.023
620	0.381	430	0.0116
610	0.503	420	0.0040
600	0.631	410	0.0012
590	0.757	400	0.0004
580	0.870		

¹ These values correspond to the \bar{y} function of the tristimulus values in the C.I.E. system.

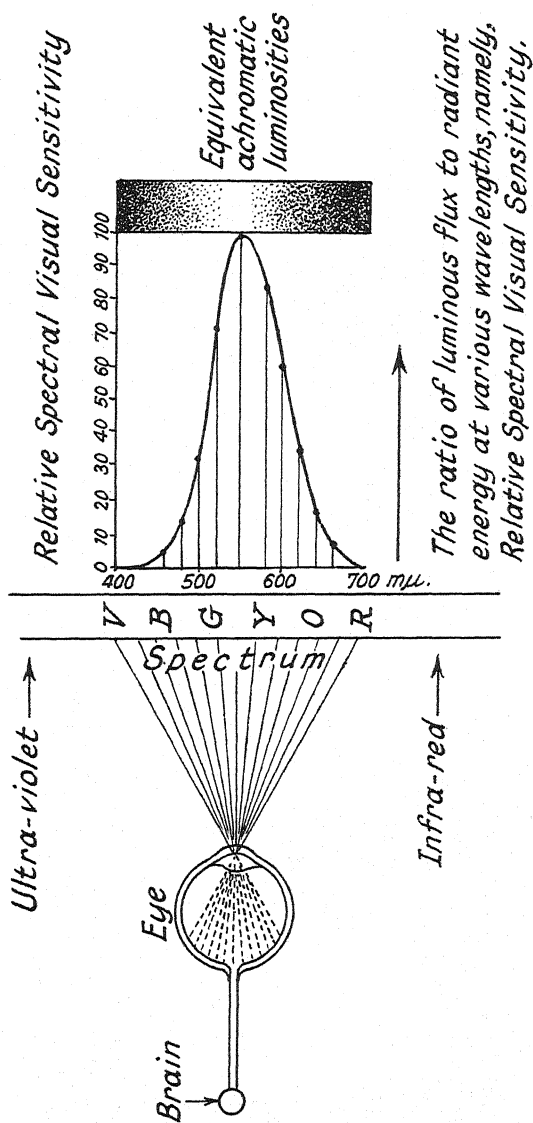


FIG. 118.—Relative Spectral Visual Sensitivity.

The visual sensitivity to radiant energy of various wavelengths of an equal energy source is judged to be slightly different by individual observers, and by the same observer under different conditions of observation, but standard data have been adopted by international agreement.

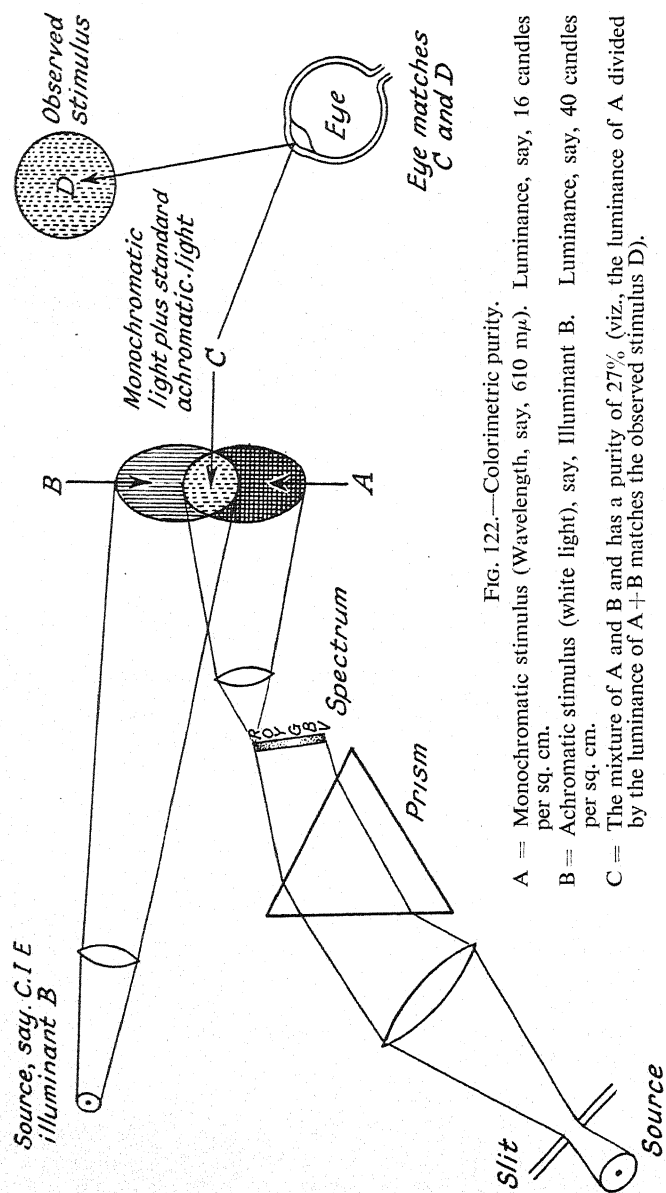


FIG. 122.—Colorimetric purity.

- A = Monochromatic stimulus (Wavelength, say, 610 $m\mu$). Luminance, say, 16 candles per sq. cm.
 B = Achromatic stimulus (white light), say, Illuminant B. Luminance, say, 40 candles per sq. cm.
 C = The mixture of A and B and has a purity of 27% (viz., the luminance of A divided by the luminance of A + B matches the observed stimulus D).

Dominant Wavelength.

In the above diagram the dominant wavelength of C is 610 $m\mu$, because this spectral stimulus added to a certain quantity of the standard achromatic stimulus (C.I.E. Illuminant C) matches the observed stimulus D.

Sensibility to Purity Differences

Any colour can be matched by mixing (adding or subtracting in the colorimetric sense) a spectral stimulus with an achromatic stimulus. The mixture is measured by *two* quantities:

1. **Dominant Wavelength**, which is defined in the report above referred to as, "The wavelength of the spectral stimulus required to be mixed (added or subtracted in the colorimetric sense) with a standard achromatic stimulus in order to match the observed stimulus." Purples are given a *complementary wavelength* if subtraction is necessary, and this is defined by the Sub-Committee on Colorimetry of the British National Illumination Committee as: "The wavelength of the portion of the spectrum which, when combined with the sample stimulus in suitable proportions, matches the adopted achromatic stimulus according to the data for the standard observer."

2. Purity.

(a) *Colorimetric Purity*, which the Physical Society Report defines as "the ratio B_d/B , where B is the luminance of the sample stimulus and B_d is the luminance of a spectral stimulus (or of a suitable combination of extreme spectral red and extreme spectral violet) which, by additive mixture with the adopted achromatic stimulus, forms a match with the sample stimulus in both luminance and chromaticity according to the data for the standard observer."

(b) *Excitation Purity*, which is, "The ratio of the distances, on a two dimensional chromaticity diagram, from the adopted achromatic stimulus to the sample stimulus and to the stimulus lying on the spectrum locus or the straight line joining its extremes, which by additive mixture with the adopted achromatic stimulus can form a match with the sample stimulus. An achromatic stimulus has purity = 0. A chromatic stimulus has purity > 0 and < 1 . A spectral stimulus has purity = 1. The dominant wavelength and purity of a stimulus correspond to the hue and saturation sensations but there is no strict parallelism. Thus, a constant hue series of increasing saturation is not necessarily a series of constant dominant wavelength, although the departure will not generally be large and may be very small for certain hues. (Since the selection of a standard illuminant is arbitrary, this close correspondence depends on whether or not the standard illuminant is acceptable as achromatic under the conditions of observation.) Dominant wavelength and purity as objective quantities are independent of luminance, but the hue and saturation sensations may vary with the luminance. Although the purity increases with saturation, a scale of equal steps of saturation does not agree with either the colorimetric or excitation purity scales. In like manner, luminance corresponds to luminosity sensation but there is no strict proportionality

since the scales of equal steps do not agree. If the luminance is specified as well as the dominant wavelength and purity relative to some standard illuminant, the colour is completely defined. This system of colour specification corresponds to the representation of a sector in polar co-ordinates. For comparing colours the characteristics of a stimulus are completely defined by three quantities—either the three trichromatic co-ordinates, or the luminance, dominant wavelength and purity. Normally it is sufficient to consider only the relative luminance of colours.”

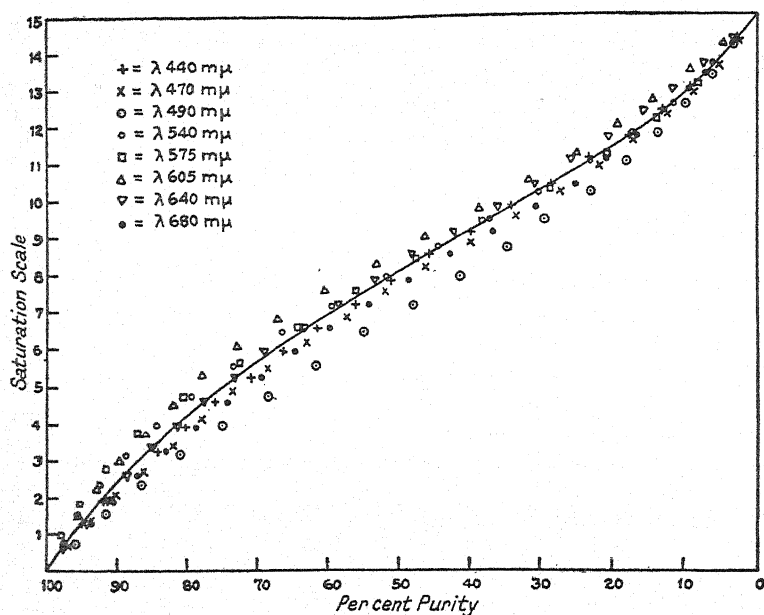


FIG. 120.—Saturation sensibility (L. A. Jones and E. M. Lowry).

Saturation, which is the subjective term corresponding to *purity*, is “that attribute of visual sensations which permits a judgment to be made of the proportion of colourfulness in the total sensation. Sensations of the same hue and luminosity can be arranged in a series of increasing saturation ranging from grey to that member of the series in which the hue appears most marked.” (Report on Colour Terminology by a Committee of The Physical Society Colour Group, London, 1948.)

L. A. Jones and E. M. Lowry [10] have determined the number of the least perceptible saturation steps between each maximally saturated colour and white (Fig. 120). The curves representing the sensibility of the eye to differences of saturation possess two maxima, one, the greater of the two, being at complete saturation, and the other at zero. Complete

saturation means that for purposes of physical specification the spectral colours are 100 per cent. saturated. An exception to the order of sensibility is found in the case of the blue-green (490 $m\mu$), for which hue the maximum appears at zero purity. The reason is unknown. It will be seen from Table 42 that the number of saturation steps varies for the

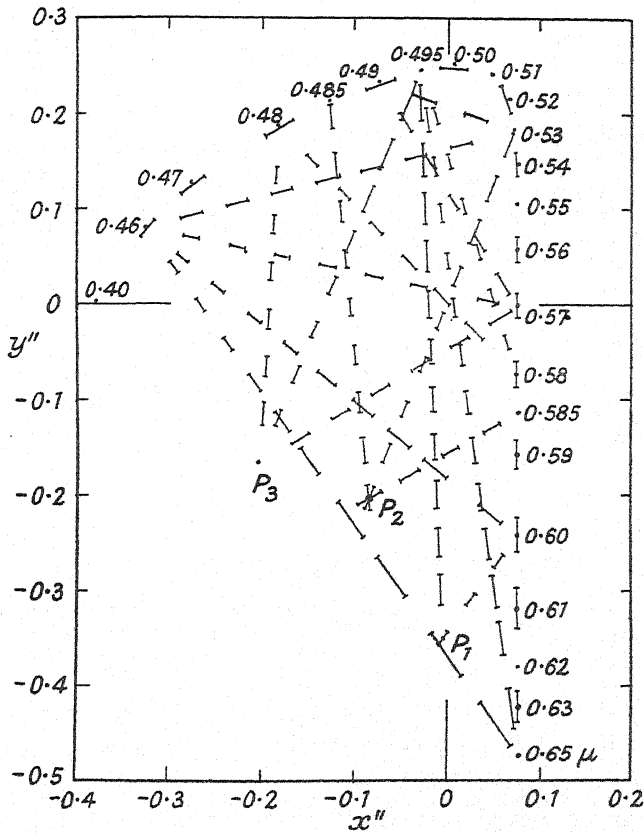


FIG. 121.—Colour steps plotted in the R.U.C.S. chart for 18 of the lines tested by W. D. Wright.

different colours, the larger number of steps being found in the red and blue, and the smaller in the yellow [11].

W. D. Wright (12) has measured comfortably discriminative steps along thirty-five lines across the C.I.E. (I.C.I.) chromaticity chart. The mean of such steps of four observers turned out to be some three times the just noticeable difference. When plotted on the standard C.I.E. chart the steps are found to be very badly distorted, and the data are much better presented on the Breckenridge and Schaub rectangular-uniform-

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chromaticity scale chart (known as the R.U.C.S.). But no linear projection of the C.I.E. diagram can give an exact equality of the colour steps. The purples and the spectrum locus were also examined.

Plotted on the C.I.E. standard chart, the smallest steps were in the blue corner and the longest in the green and yellow.

For Wright the steps on the R.U.C.S. chart all vary between 0.017 and 0.034 of the length of the line joining two wavelengths (Fig. 121).

TABLE 42.—SATURATION SCALE DATA (JONES AND LOWRY)

Step No.	Wavelengths in $M\mu$ (Percentage Purity).							
	440.	470.	490.	540.	575.	605.	640.	680.
1	97.5	97.0	96.0	98.0	98.0	98.0	97.2	97.0
2	95.0	93.7	91.5	95.8	95.2	95.5	94.3	93.3
3	92.0	90.2	86.5	92.5	91.5	92.8	91.4	90.5
4	88.5	86.2	81.0	88.8	86.9	89.7	88.4	87.0
5	84.4	82.0	75.0	84.5	80.5	86.0	85.0	83.0
6	80.3	78.0	68.5	79.5	72.5	82.0	81.5	78.8
7	76.0	73.5	61.5	73.5	64.3	77.7	77.5	74.4
8	71.0	68.5	54.8	66.5	55.8	72.8	73.5	69.5
9	66.4	63.0	47.7	59.2	47.4	67.0	69.0	64.7
10	61.5	57.4	41.0	51.5	38.0	60.3	64.0	59.7
11	56.0	51.8	34.5	44.4	28.5	53.0	58.5	54.2
12	51.0	46.0	28.3	37.0	20.5	45.8	52.5	48.5
13	45.5	39.7	22.8	30.0	13.7	38.5	47.0	42.5
14	39.7	33.4	17.9	23.0	8.0	31.4	41.5	36.5
15	34.0	27.0	13.5	17.0	3.5	24.8	25.7	30.5
16	28.3	21.5	9.6	11.2	0.0	19.0	30.5	25.0
17	23.0	17.0	6.0	6.5		14.2	25.4	20.6
18	17.5	12.3	2.8	2.7		9.0	20.2	16.5
19	13.0	8.5	0.0	0.0		4.5	15.5	12.8
20	9.0	5.0				0.0	11.5	9.3
21	5.7	2.3					7.1	6.0
22	2.5	0.0					3.3	2.8
23	0.0						0.0	0.0

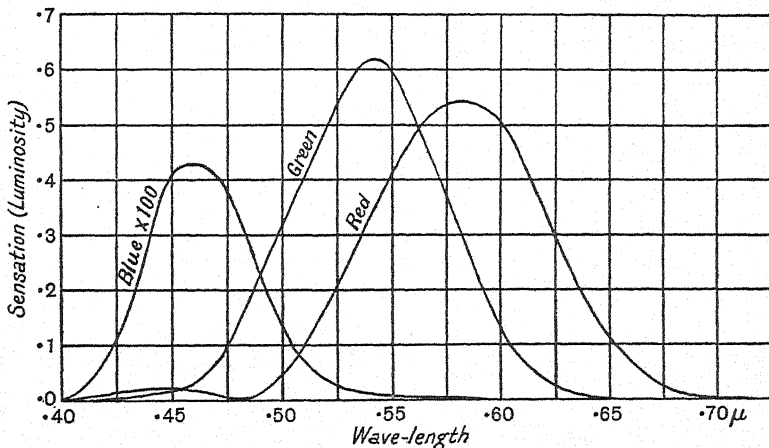
Trichromatic Colour Mixture

The experimental fact that practically every colour can be matched by the admixture of three colours is *independent of any theory of colour vision advanced to account for it*. The reader is referred, for a study of the theories of colour vision, to the literature of the subject. Here we have only to note that, were it not that most colours can be matched by the admixture of three, colour photography, as we know it *so far*, would not exist. But it is always interesting and suggestive to recall that the three-colour method need not be the final solution, for if we can discover some light-sensitive substance capable of assuming the colour

of the light to which it is exposed (or the complementary colour thereto) and the means be found for fixing it, there would no longer be any need for *three-colour* photography.

So that the Young-Helmholtz theory of colour vision is immaterial to the facts with which we, as colour photographers, should be acquainted. The colour-receiving apparatus would appear from the facts to have three functions of some sort or other (see Granit), but the true explanation of what happens has formed the subject of argument, and sometimes acrimonious argument, for the lasty sixty years or so. And there we propose to let the matter rest.

It is very helpful, however, to represent the three sensations hypothesized, as a means of conceiving what *may* underlie the facts of colour



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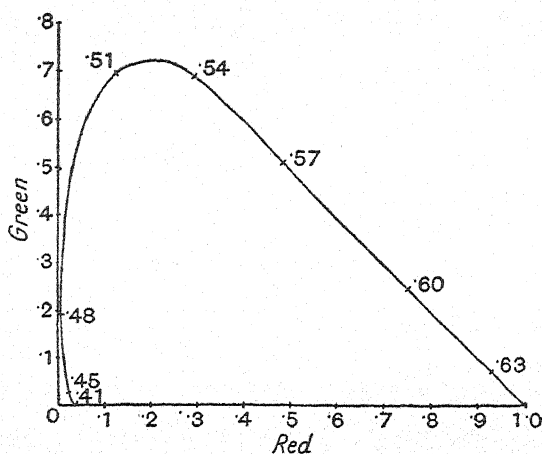
FIG. 123.—Sensation (luminosity) curves for white light spectrum (arbitrarily selected primaries) (W. D. Wright).

mixture. Three primaries are chosen such that all visible radiations stimulate positive amounts of them. Now a stimulus of some given energy distribution will produce a sensation which may be regarded as the composite effect of three component sensations. The proportions in which the three primaries are stimulated are measured on a *luminosity* basis, as this quality is the only one they have *in common* (we know that blue is less bright than yellow, for example). As W. D. Wright well expresses it:

The fact that it is difficult, when making a direct comparison, to determine the exact point at which two different colours have the same luminosity (brightness) is the result of a marked difference of one quality dulling the observer's sensitivity to a small difference in another quality, and does not signify that the common quality of luminosity is non-existent.

Fig. 123 gives the relative luminosity of the three sensations in the various spectrum hues, referred to a white light spectrum ($5,000^{\circ}$ K.). The areas under the three curves give the proportion stimulated by the integral light of the spectrum.

The next thing is to separate the hue part of the sensation from the luminosity. To do this we must adopt the convention that equal amounts of the three primary sensations make white. We have to find factors for making the areas under the three curves equal. These factors enable us to express a colour *apart* from its luminosity as certain amounts of red, green, and blue, multiplied by the equality factors and expressed as coefficients adding up to unity. This is called a *trichromatic*



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FIG. 124.—Colour triangle (chromaticity diagram) showing spectral locus referred to hypothetical primaries (W. D. Wright).

unit. Such a unit fulfils mathematical laws. If we mix X units of a colour C_1 with X units of another colour C_2 , then we have $2X$ units of some third colour C_3 , and so on.

This system has led to the use of the triangular method of representing a colour. An equilateral triangle has generally been used, but this method uses a superfluous co-ordinate in that once two out of the three coefficients are known the third is given by the difference from unity of the sum of the two. Hence a two co-ordinate system is feasible, and has the advantage of possessing rectangular axes.

In Fig. 124 the abscissa of a point gives its red and the ordinate its green coefficient, and these completely determine the colour represented by the point. The units being based on equal quantities of the primaries matching white, the white point has the co-ordinates (0.333, 0.333). The position of the spectrum hues is shown. A colour which is

the mixture of two others will lie in the straight line joining the points locating these. It follows from the properties of the colour triangle that the colour resulting from any visible radiation must fall inside the area

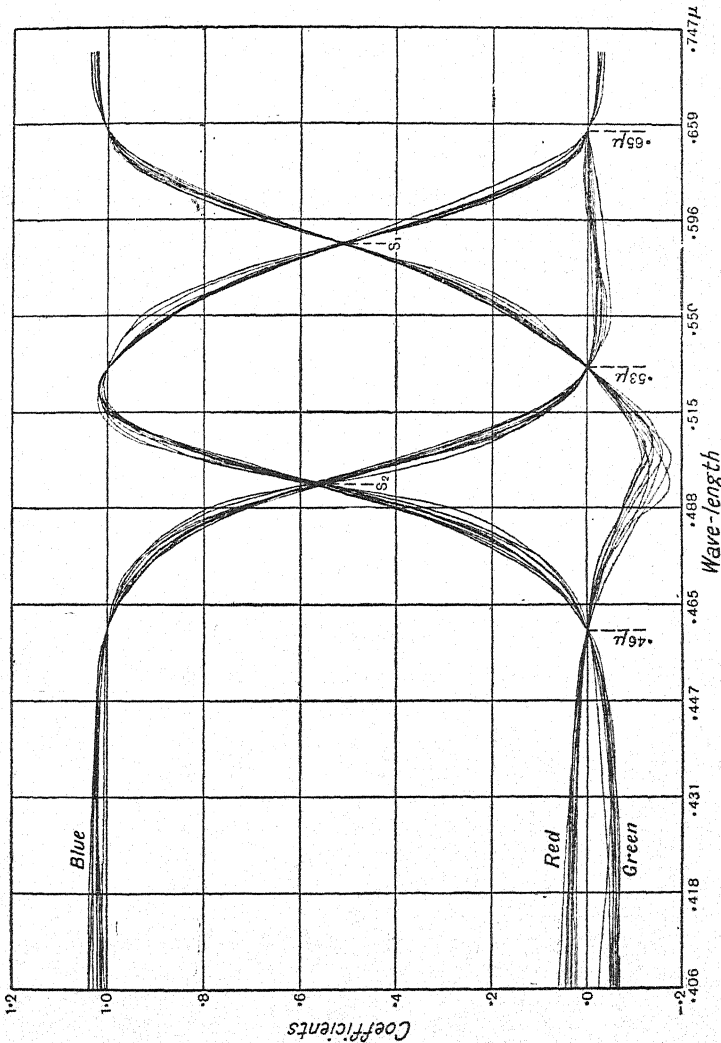


FIG. 125.—Superimposed distribution coefficient curves of 10 observers (W. D. Wright).
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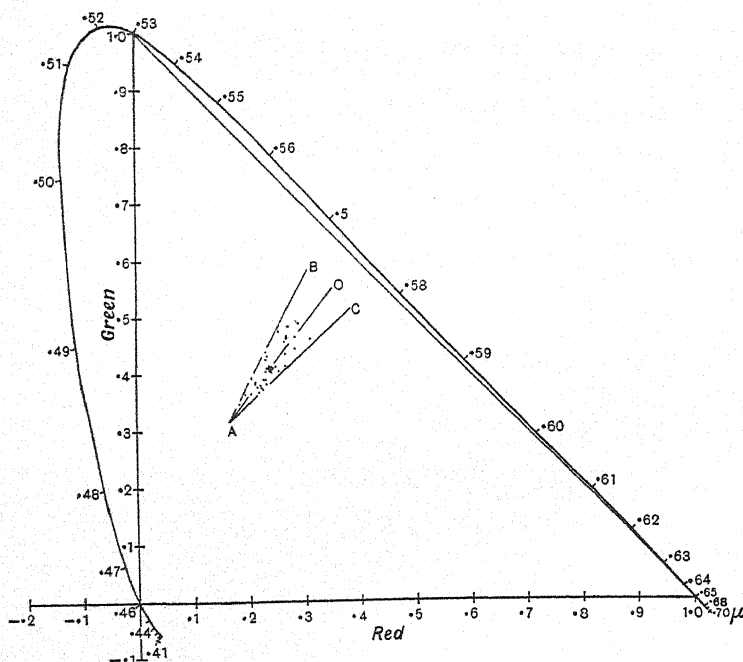
bounded by the spectrum hues, since such a colour must be composed of one or more monochromatic radiations.

The primaries in the above figure are impossible to match (nor have we any normal experience of them) without assuming negative values. The negative coefficient can be found by adding sufficient of the primary

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concerned to the spectral colour until the mixture can be matched, and then measuring the amount of desaturating primary introduced. Subtraction of this quantity from the quantity of the primary in the mixture gives the required negative amount of primary.

W. D. Wright's famous determination of the trichromatic data, averaged with that obtained by J. Guild of the National Physical Laboratory, was adopted by the International Commission on Illumination in 1931 as the basis for the C.I.E. (I.C.I.) tristimulus values. The



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FIG. 126.—Colour triangle showing mean spectral locus of 10 observers and white points of 36 observers (W. D. Wright).

mean wavelengths of the primaries used by Wright were $650\text{ M}\mu$ red, $530\text{ M}\mu$ green, and $460\text{ M}\mu$ blue.

“ Provided the coefficients of one set of primaries are known in terms of another set, the coefficients of any colour expressed in one system can be expressed on the other system simply by means of arithmetical transformations. This is important, as it at once follows that it is of no theoretical consequence what primaries are used—since the results can be transferred to another set if desired. The idea that special primaries must be used is false and the practical advantages of one set over another one are all that have to be considered ” (W. D. Wright).

In Fig. 71 is shown the mean set of curves obtained from Fig. 125. It

must be remembered that these are mixture curves and have no theoretical significance, as they are not sensation curves.

The data of Fig. 125 are represented in Fig. 126 by the spectral locus, the scale along the line giving wavelength in microns. Note that the difference between this triangle and the triangle in Fig. 124 is due to the use of hypothetical primaries in the first case and real primaries in the second. Inside the triangle Wright has plotted the "white points" of 36 observers. The variation in the position of white is concluded to be due to the variation in the density of the macula pigment and its variation in dominant hue. The variation is surprisingly big.

For detailed treatment of the methods by which the tristimulus values were calculated the reader is referred to the original paper [13].

Colorimetry

The C.I.E. (I.C.I.) Trichromatic System

1. A normal observer can match any colour stimulus by mixing the light from three suitably chosen stimuli in the proper proportions, but the matching of spectral radiations involves the use of negative coefficients.
2. Colour-mixture data have been determined for an internationally accepted group of observers by use of a colorimeter with which chosen primaries were mixed to match monochromatic light throughout the spectrum.
3. In 1922 the Colorimetry Committee of the Optical Society of America published standard data. In 1928 Guild and Wright re-determined these fundamental data, and the International Commission on Illumination standardized the data in 1931.
4. All sets of real stimuli make it necessary to use negative amounts of at least one of the primaries. To avoid negative amounts stimuli must be used which could have no actual existence. Such imaginary REFERENCE STIMULI have been adopted in the C.I.E. System and are known as X, Y, Z. The units are so chosen as to make a mixture of equal quantities of the three homogeneous stimuli chromatically equivalent to a heterogeneous stimulus for which the total energy of the radiation of all wavelengths between any two limiting wavelengths within the visible spectrum is a constant multiple of the difference between these limiting wavelengths. The relative luminosities of the units of the three homogeneous stimuli for the *Standard Observer* are in the ratio 1: 4.5907: 0.0601. These stimuli are generally denoted as R, G, B.
5. The four stimuli, known as *CARDINAL STIMULI*, which define the standard colorimetric scales consist of homogeneous radiations of wavelengths 700 M μ , 546.1 M μ and 435.8 M μ and the radiation

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from standard Illuminant B. These stimuli are assigned the following values:

0.73467 X+0.26533 Y+0.00000 Z for 700 M μ .
 0.27376 X+0.71741 Y+0.00883 Z for 546.1 M μ .
 0.16658 X+0.00886 Y+0.82456 Z for 435.8 M μ .
 0.34842 X+0.35161 Y+0.29997 Z for Illuminant B.
 0.33333 X+0.33333 Y+0.33333 Z for Equal-energy Stimulus.

6. The *DISTRIBUTION COEFFICIENTS* of these stimuli in an equal energy spectrum are denoted by \bar{x} , \bar{y} , \bar{z} in the C.I.E. System and defined as a table of figures which represents the characteristics of the *Standard Observer* (see table below). The values indicate the amount of each of X, Y, Z, required to match a unit quantity of radiant energy of the various wavelengths.
7. The three co-ordinates of a colour in the C.I.E. system are known as *CHROMATICITY CO-ORDINATES* and are denoted by x, y, z. These quantities are respectively $u/(u+v+w)$, $v/(u+v+w)$ and $w/(u+v+w)$, where

$$u = \frac{\int S_{\lambda} E_{\lambda} \bar{x} d\lambda}{\int E_{\lambda} \bar{y}_{\lambda} d\lambda}$$

$$v = \frac{\int S_{\lambda} E_{\lambda} \bar{y}_{\lambda} d\lambda}{\int E_{\lambda} \bar{y}_{\lambda} d\lambda}$$

$$w = \frac{\int S_{\lambda} E_{\lambda} \bar{z}_{\lambda} d\lambda}{\int E_{\lambda} \bar{y}_{\lambda} d\lambda}$$

S=Spectral reflection or transmission factor of the body.
 and E_{λ} =Spectral distribution of the illuminant.

8. u, v, w, respectively are the amounts of R, G, B (or in the case of the C.I.E. system, X, Y, Z), required to match a colour C measured in some convenient unit. u, v and w are known as *TRISTIMULUS VALUES*.

C can be expressed algebraically by the equation

$$C=u.R+v.G+w.B$$

9. The C.I.E. trichromatic system of colour specification employs three imaginary reference stimuli denoted (see para. 4) by X, Y, Z. The X and Y co-ordinate axes are chosen to lie in the plane of the alychne.¹ They therefore have zero luminance so that the

¹ Alychne.—The locus in a trichromatic co-ordinate system of colours of zero luminance. It is a plane passing through the origin and lying wholly outside the boundary of realizable colours.

relative luminance of any stimulus is given directly by its Y co-ordinate. The XY plane of the System is made tangential to the red end of the spectrum locus (which approaches a plane in this region) and the YZ plane passes close to the spectrum locus, without touching, in a direction which gives a favourable disposition of the spectrum locus within the sector formed by the co-ordinate axes. The C.I.E. tristimulus values u , v , w are therefore positive for all real stimuli including spectral colours. An equal energy stimulus is used for the basic stimulus (1).

Standard Colour-Mixture Data

The colour-mixture curves (Tristimulus Values) upon which the C.I.E. colorimetric system is based are geometrical, linear transformations of Wright's and Guild's curves averaged (J. Guild, *Phil. Trans. Roy. Soc.*, A230, 149, 1931). These two sets of curves possessed negative values for some wavelengths. The C.I.E. curves are conveniently computed so as to have no negative values, and they correspond to wholly hypothetical fundamental stimuli, and, moreover, the green curve has been made identical with the relative spectral luminance function (see page 224). Of course, no actual observations of the mixture values of real colours of the spectrum or otherwise could possibly result in such curves; nevertheless they express and include the factual data upon which they are based. The whole system has been devised for convenience of calculation. The ordinates of the curves are expressed in arbitrary units so as to make the areas under each curve equal when the data are plotted to equal scales.

As we have had previous occasion to remark, such colour-mixture data are absolutely independent of all theories of colour vision. They are based on a phenomenal fact, the possibility of matching practically all colours with three. They do not explain why this is a fact. *The knowledge of this fact would have been enough upon which to base the methods by which colour photography has been achieved without taking into consideration any hypothesis of the mechanism of colour vision, whether it be that of Helmholtz or, in our day, Granit.*

The chromaticity co-ordinates of a given sample of radiant energy are computed by integrating the product of the ordinates of one of the standard mixture curves multiplied by the distribution of energy wavelength by wavelength in the sample. In the case of reflected radiant energy the spectral composition is the product of the incident energy and the radiant reflectance of the surface. The chromaticity co-ordinates so calculated are made numerically equal to the directional luminous reflectance of the surface for a given distribution of radiant energy. Chromaticity co-ordinates of the radiant transmittance of a sample are calculated in the same fashion.

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Specification of Chromaticity in the Chromaticity Diagram

Chromaticity can be specified by use of the proportions which two of the chromaticity co-ordinates bear to the total of the three chromaticity co-ordinates. These two proportions can be employed as co-ordinates for the representation of the chromaticity of a sample by the position

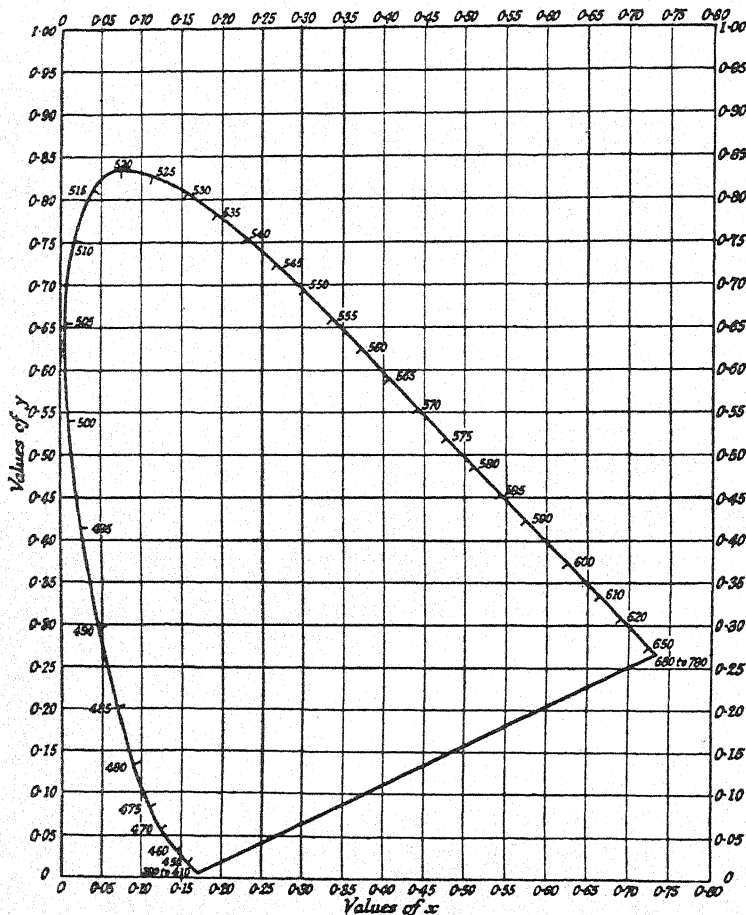


FIG. 127.—The spectral locus plotted on a rectangular diagram.

of a point in a plane diagram. Such a diagram is called a *chromaticity diagram* [14].

The chromaticities of the spectrum colours can be computed by dividing the ordinate of each of the colour-mixture curves at the appropriate wavelength by the sum of the ordinates of the three curves at that wavelength. The locus of the spectrum is the curve on the chromaticity chart in Fig. 127. The horizontal co-ordinate representing each

spectrum colour is the ratio of the ordinate of \bar{x} in Fig. 55 to the sum of the ordinates at that wavelength of \bar{x} , \bar{y} and \bar{z} . The vertical co-ordinate is the ratio of the ordinate \bar{y} in Fig. 55 at the indicated wavelength to the sum of the ordinates. It will be seen that the curve defined by the co-ordinates representing the chromaticities of energy of the various wavelengths is smooth and continuous, and that its extremities are quite far apart. The point representing the chromaticity of the light from a source radiating equal amounts in equal intervals of wavelength throughout the spectrum has the co-ordinates 0.3333, 0.3333. These co-ordinates result from the fact that the integrals which give the tristimulus values of such light are proportional to the areas under the three colour-mixture curves, which three areas are all equal.

C.I.E. Standard Illuminants

1. Daylight consists of a mixture of all the components of the visible spectrum in nearly equal proportions. At the C.I.E. meeting in 1931 a light-source was adopted having a distribution of energy given by a filter used in conjunction with a tungsten lamp operated at a standardized temperature providing a source closely approximating daylight. This source is known as C.I.E. Illuminant C.
2. Two other standards were adopted—Illuminants A and B.

A is a projector-type gas-filled tungsten filament lamp burning at a colour-temperature of 2,848° K. C.I.E. Illuminant B represents the yellower phases of daylight and is obtained by filtering Illuminant A with liquid solutions in a double glass cell. The colour of this filter with standard Illuminant A as an illuminant is 0.3482 X + 0.35161 Y + 0.29997 Z (Smith and Guild, 1931). The transmittance is 24.9 per cent. and the colour-temperature 4,860° K.

Luminance

In order to record the relative luminance of a colour at the same time as its tristimulus values it was decided to make one of the three functions (viz., \bar{y}) correspond with the relative spectral luminance function for the light-adapted eye. Hence the relative spectral luminance of a colour is indicated directly by the value of Y on a scale that represents an absolute black by zero and a perfect white by 100.

Illuminant C

The light-source is a tungsten lamp operated at a temperature of 2,848° K. The National Physical Laboratory can supply lamps which have been properly calibrated and aged. The filter consists of a double glass cell (white optical glass), each layer being 1 cm. thick, of the following solutions, C₁ and C₂:

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Solution C₁.

Copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$)	3.412 gm.
Mannite ($\text{C}_6\text{H}_8(\text{OH})_6$)	3.412 "
Pyridine ($\text{C}_5\text{H}_5\text{N}$)	30.0 c.c.
Distilled water to make	..	..	..	1000.0 "

Solution C₂.

Cobalt-ammonium sulphate ($\text{CoSO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$)	..	..	..	30.580 gm.
Copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$)	..	..	..	22.520 "
Sulphuric acid (density 1.835)	..	..	..	10.0 c.c.
Distilled water to make	..	..	..	1000.0 "

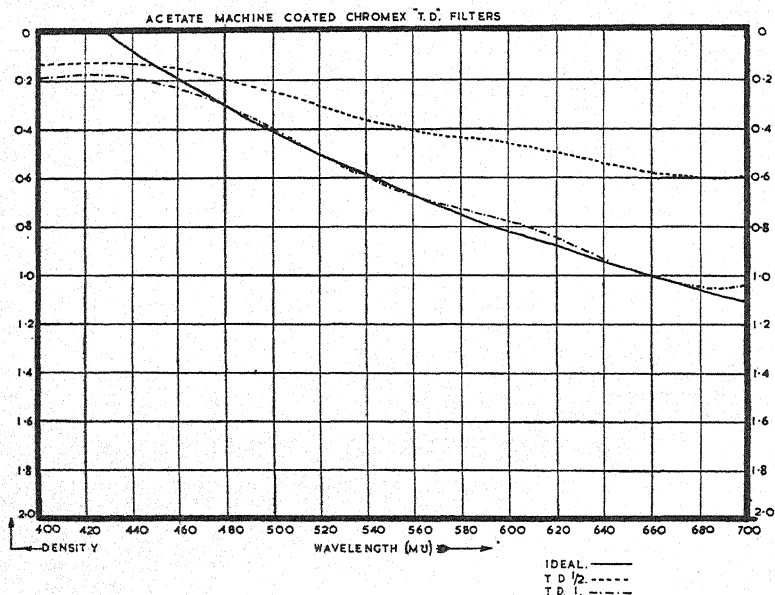


FIG. 128.—Spectral transmission of Chromex "T.D." filter compared with a colour-temperature-raising filter of ideal characteristics. (Courtesy, Dufay-Chromex Ltd.)

Dufay-Chromex Ltd. manufacture a colour-temperature-raising filter known as "T.D." which gives an exceedingly close approximation to the calculated ideal. The accuracy of colour rendering of Illuminant C is to within 0.005 in y value on the C.I.E. (I.C.I.) chart for any initial colour-temperature and for all corrections normally used. For Illuminant B the accuracy is within 0.002. It is stable both to heat and light. This remarkable filter is in some respects superior to the liquid filters, with the obvious advantages of lower cost and ease of manipulation. It is available in gelatine or cellulose acetate or cemented in glass of any specified quality. T.D. $1\frac{1}{2}$ is the equivalent of Illuminant C, and T.D. 1 raises the colour-temperature from Illuminant A to Illuminant B (Fig. 128).

The procedure of evaluating the chromaticity co-ordinates (x, y, z) of a colour is much simplified by use of the tables available in Professor Arthur C. Hardy's *Handbook of Colorimetry* [11]. These give amongst other data the product between the C.I.E. illuminants and the distribution coefficients (according to Judd). The spectral transmittance or reflectance values are multiplied wavelength by wavelength by the values

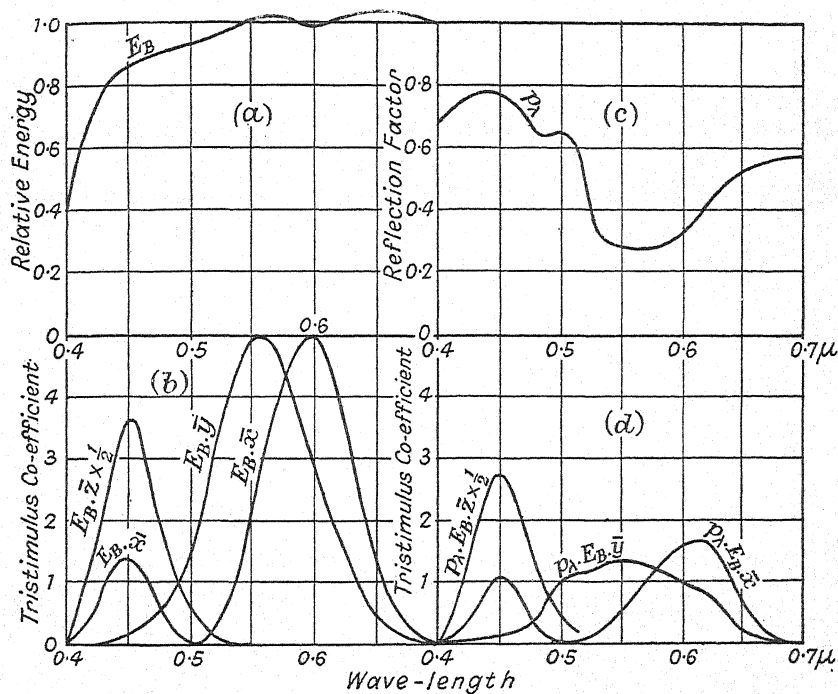


FIG. 129.—The calculation of the tristimulus specification for a coloured surface. (a) The energy distribution of the illuminant. (b) The product of (a) with the distribution curves of Fig. 55. (c) The spectral reflection curve of the surface. (d) The product of (b) and (c) to give the tristimulus curves of the surface. The areas under the three curves give the amounts of X, Y and Z required to match the surface (W. D. Wright).

of $E_c \bar{x}$ (where E_c is the energy distribution of C.I.E. Illuminant C^1 and \bar{x} is the tristimulus value for the red primary). The product is summed for all wavelengths, and this process is repeated for \bar{y} and \bar{z} .

¹ Illuminant C corresponds with a black body at 6,500° K.

Illuminant B corresponds with a black body at 4,800° K.

Illuminant E (equal energy spectrum) is off the total radiator locus, but is estimated to lie between 5,250° K. and 5,450° K. (H. G. W. Harding).

Illuminant D (lightly overcast sky) corresponds to a total radiator at 7,500° K.

Illuminant S (very blue sky), 60,000° K.

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This gives the values of X , Y , and Z .

The chromaticity co-ordinates x , y , z are then derived as follows:

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

Only two of these quantities are independent, since $x+y+z=1$, regardless of the values assigned to x , y and z . Hence, to specify the chromaticity of a sample it is necessary to give the values of only two of the three quantities (x and y have generally been selected for this purpose). Thus x and y are the chromaticity co-ordinates of the light, pigment, or dye to be specified.

In the case of a glass, the transmittance can be determined for a given illuminant by finding the *ratio* of the value of Y for this glass to the value of Y for a hypothetical glass whose transmittance is 1.000 for every wavelength. The values of X , Y , Z for Illuminant C in Hardy's tables are

$$\left. \begin{array}{l} X=1,044 \\ Y=1,064 \\ Z=1,257 \end{array} \right\} \text{Product of illuminant distribution of energy and } \bar{x}, \bar{y}, \bar{z}.$$

Thus

$$\frac{Y \text{ (value for the sample)} \times 100}{Y \text{ (1.00 transmission for all wavelengths)}} = \text{visual transmittance per cent.}$$

In the case of Illuminant C the value of Y for 1.000 transmittance or reflectance at all wavelengths equals 1,064.

Exactly the same method is pursued for determination of the visual efficiency of the reflected light from a pigment, dye, etc.

Note.—The symbols \bar{x} , \bar{y} , \bar{z} denote distribution coefficients for spectrum colours (equal energy).

The symbols x , y , z denote chromaticity co-ordinates for the sample (or a spectrum colour).

The distribution coefficients that were adopted by the International Commission on Illumination for the various spectrum colours are given in the accompanying Table 43. The values of \bar{x} , \bar{y} , \bar{z} indicate the amount of the C.I.E. primaries required to match a unit quantity of the various wavelengths.

TABLE 43.—C.I.E. DISTRIBUTION COEFFICIENTS \bar{x} , \bar{y} , \bar{z} THROUGH THE
EQUAL-ENERGY SPECTRUM. (C.I.E. TRISTIMULUS VALUES.)
(ABRIDGED)

<i>Wavelength (Millimicrons).</i>	\bar{x} .	\bar{y} .	\bar{z} .
400	0.0143	0.0004	0.0679
410	0.0435	0.0012	0.2074
420	0.1344	0.0040	0.6456
430	0.2839	0.0116	1.3856
440	0.3483	0.0230	1.7471
450	0.3362	0.0380	1.7721
460	0.2908	0.0600	1.6692
470	0.1954	0.0910	1.2876
480	0.0956	0.1390	0.8130
490	0.0320	0.2080	0.4652
500	0.0049	0.3230	0.2720
510	0.0093	0.5030	0.1582
520	0.0633	0.7100	0.0782
530	0.1655	0.8620	0.0422
540	0.2904	0.9540	0.0203
550	0.4334	0.9950	0.0087
560	0.5945	0.9950	0.0039
570	0.7621	0.9520	0.0021
580	0.9163	0.8700	0.0017
590	1.0263	0.7570	0.0011
600	1.0622	0.6310	0.0008
610	1.0026	0.5030	0.0003
620	0.8544	0.3810	0.0002
630	0.6424	0.2650	0.0000
640	0.4479	0.1750	0.0000
650	0.2835	0.1070	0.0000
660	0.1649	0.0610	0.0000
670	0.0874	0.0320	0.0000
680	0.0468	0.0170	0.0000
690	0.0227	0.0082	0.0000
700	0.0114	0.0014	0.0000

TABLE 44.—CHROMATICITY CO-ORDINATES OF THE SPECTRUM
(SEE FIG. 127)

<i>Wavelength (Millimicrons).</i>	<i>x.</i>	<i>y.</i>	<i>z.</i>
400	0.1733	0.0048	0.8219
410	0.1726	0.0048	0.8226
420	0.1714	0.0051	0.8235
430	0.1689	0.0069	0.8242
440	0.1644	0.0109	0.8247
450	0.1566	0.0177	0.8257
460	0.1440	0.0297	0.8263
470	0.1241	0.0578	0.8181
480	0.0913	0.1327	0.7760
490	0.0454	0.2950	0.6596
500	0.0082	0.5384	0.4534
510	0.0139	0.7502	0.2359
520	0.0743	0.8338	0.0919
530	0.1547	0.8059	0.0394
540	0.2296	0.7543	0.0161
550	0.3016	0.6923	0.0061
560	0.3731	0.6245	0.0024
570	0.4441	0.5547	0.0012
580	0.5125	0.4866	0.0009
590	0.5752	0.4242	0.0006
600	0.6270	0.3725	0.0005
610	0.6658	0.3340	0.0002
620	0.6915	0.3083	0.0002
630	0.7079	0.2920	0.0001
640	0.7190	0.2809	0.0001
650	0.7260	0.2740	0.0000
660	0.7300	0.2700	0.0000
670	0.7320	0.2680	0.0000
680	0.7334	0.2666	0.0000
690	0.7344	0.2656	0.0000
700	0.7347	0.2653	0.0000

Thus, referring to Table 43, the wavelength 550 $M\mu$ has tristimulus values of 0.433 (\bar{x}), 0.995 (\bar{y}), and 0.009 (\bar{z}). Now $\bar{x} = X + Y + Z$, and from the addition of $0.433 + 0.995 + 0.009$ we get 1.439; x will therefore be equal to $0.433/1.439$ or 0.30 (the value in the above table), and, similarly, y will be equal to $0.995/1.439$ or 0.69.

RECTANGULAR UNIFORM CHROMATICITY SCALE CO-ORDINATES (F. C. BRECKENRIDGE AND W. R. SCHAUB)—FORMULÆ AND TABLES

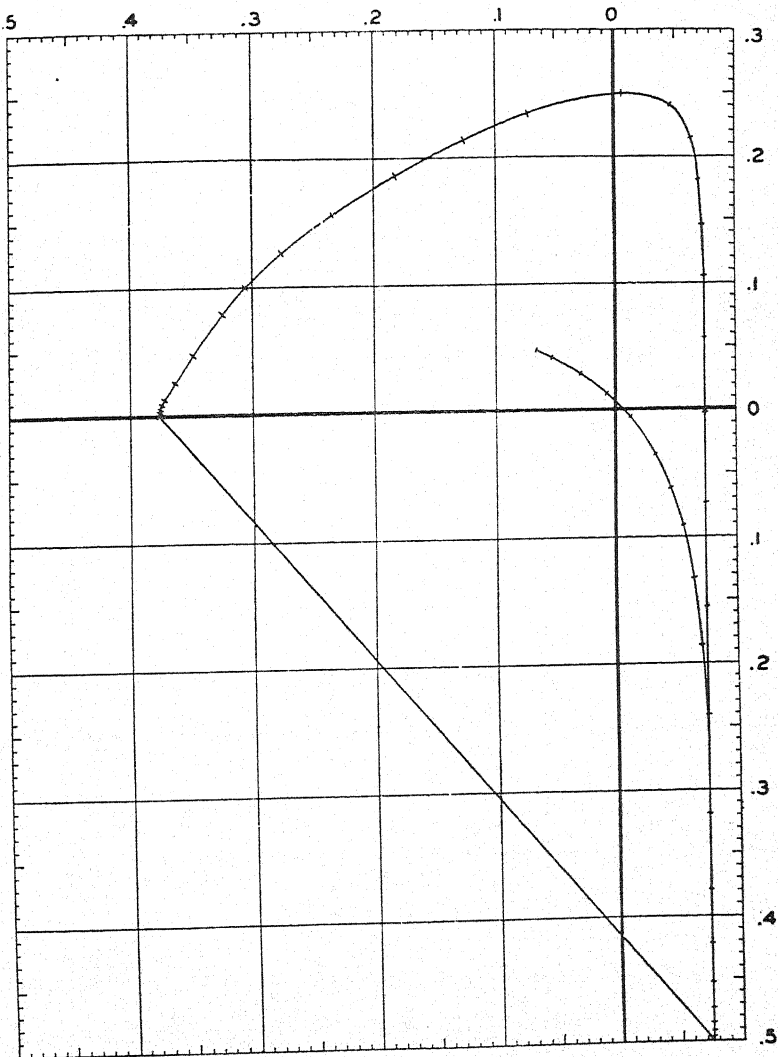


FIG. 130.—R.U.C.S. Chromaticity diagram (Breckenridge and Schaub).

General transformation equations for transforming tristimulus coefficients—

(a) I.C.I. into R.U.C.S.:

$$\begin{aligned} \bar{x}' &= +0.00000 \bar{x} + 0.00000 \bar{y} + 0.82303 \bar{z}, \\ \bar{y}' &= -2.32804 \bar{x} + 6.44609 \bar{y} + 1.36896 \bar{z}, \\ \bar{z}' &= +2.96827 \bar{x} + 2.24750 \bar{y} - 0.55176 \bar{z}. \end{aligned} \quad (a)$$

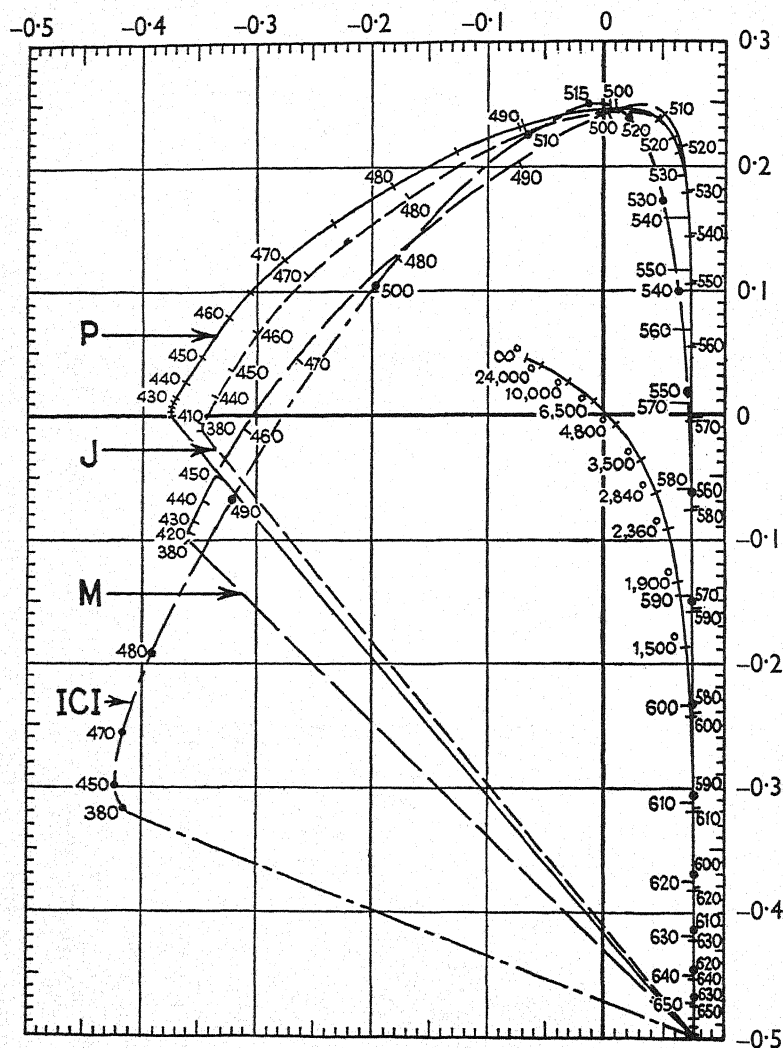


FIG. 130A.—Comparison of three uniform-chromaticity-scale diagrams with C.I.E. diagram. *J*, Judd's diagram; *M*, MacAdam's modification; *P*, Modification proposed by Breckenridge and Schaub. Planckian locus is in accordance with *P*. The diagrams have been rotated and contracted to facilitate comparison of spectrum colours (Breckenridge and Schaub).

(b) R.U.C.S. into I.C.I.:

$$\begin{aligned} \bar{x} &= +0.33078 \bar{x}' - 0.09224 \bar{y}' + 0.26455 \bar{z}', \\ \bar{y} &= -0.13857 \bar{x}' + 0.12182 \bar{y}' + 0.09554 \bar{z}', \\ \bar{z} &= +1.21502 \bar{x}' + 0.00000 \bar{y}' + 0.00000 \bar{z}'. \end{aligned} \quad (b)$$

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TABLE 45.—TRISTIMULUS DISTRIBUTION COEFFICIENTS FOR COMPUTING
R.U.C.S. CO-ORDINATES ($\lambda=770 M\mu$ at $x'=0, y'=0$)
(BRECKENRIDGE AND SCHAUB)

Equal Energy Source.			Wave-length ($M\mu$).	Planckian Source* at 2,355° K.			Wave-length ($M\mu$).	Planckian Source* at 2,842° K.		
\bar{x}' .	\bar{y}' .	\bar{z}' .		$\bar{x}'E$.	$\bar{y}'E$.	$\bar{z}'E$.		$\bar{x}'E$.	$\bar{y}'E$.	$\bar{z}'E$.
540	601	60	380	2	3		380	6	7	1
1,655	1,840	180	390	10	11		390	23	25	2
5,637	2,272	598	400	43	48	5	400	94	104	10
16,926	18,881	1,731	410	165	184	17	410	338	377	35
53,158	59,701	5,164	420	652	732	63	420	1,260	1,415	122
144,040	131,058	10,437	430	1,741	2,001	159	430	3,175	3,649	291
143,224	172,292	12,121	440	2,689	3,234	228	440	4,641	5,584	393
145,898	188,900	10,524	450	3,328	4,309	240	450	5,450	7,056	393
137,388	199,471	7,729	460	3,765	5,466	212	460	5,865	8,515	330
106,008	189,497	7,379	470	3,456	6,178	241	470	5,131	9,173	357
66,899	178,611	14,777	480	2,570	6,861	568	480	3,644	9,728	805
38,277	190,293	30,589	490	1,718	8,543	1,373	490	2,330	11,383	1,862
22,387	244,300	59,046	500	1,164	12,704	3,070	500	1,513	16,512	3,991
13,018	343,721	107,089	510	778	20,546	6,401	510	971	25,637	7,987
6,441	453,656	174,035	520	439	30,953	11,874	520	527	37,135	14,246
3,469	522,900	240,525	530	268	40,441	18,602	530	310	46,719	21,490
1,676	550,141	299,483	540	146	47,927	26,091	540	163	53,387	29,063
722	541,672	351,908	550	70	52,833	34,314	550	76	56,824	36,906
317	503,519	399,868	560	34	54,679	43,423	560	36	56,849	45,146
170	463,510	440,085	570	20	52,501	52,931	570	21	52,829	53,262
126	347,718	467,410	580	17	46,076	61,936	580	16	44,926	60,391
95	249,134	474,790	590	14	36,198	68,984	590	13	34,240	65,253
63	159,622	456,996	600	10	25,323	72,501	600	9	23,254	66,576
31	90,825	410,697	610	5	15,661	70,819	610	5	13,982	63,223
16	46,704	339,243	620	3	8,719	63,333	620	3	7,573	55,007
7	21,271	250,248	630	1	4,283	50,394	630	1	3,622	42,613
3	8,548	172,265	640	1	1,850	37,283	640	1	1,525	30,726
0	2,969	108,205	650		688	25,082	650		553	20,161
	926	62,664	660		229	15,508	660		180	12,167
	283	33,136	670		74	8,728	670		57	6,688
	71	17,702	680		20	4,948	680		15	3,706
	7	8,573	690		2	2,536	690		1	1,858
	0	4,291	700			1,340	700			961
		2,198	710			723	710			507
		1,099	720			379	720			261
		544	730			197	730			133
		262	740			99	740			66
		125	750			50	750			32
		63	760			26	760			17
		31	770			13	770			8
878,191	5,861,914	4,983,771	Totals	23,109	489,277	684,691	Totals	35,622	533,036	647,046
x' .	y' .	z' .	Source	x' .	y' .	z' .	Source	x' .	y' .	z' .
0.074906	0.499998	0.425096	Source	0.019305	0.408726	0.571969	Source	0.029302	0.438459	0.532240

Let $X' = \Sigma \bar{x}' E \lambda$, or $\Sigma \bar{x}' E \lambda$, $Y' = \Sigma \bar{y}' E \lambda$, or $\Sigma \bar{y}' E \lambda$, $Z' = \Sigma \bar{z}' E \lambda$, or $\Sigma \bar{z}' E \lambda$, $S' = X' + Y' + Z'$.
 $x' = X'/S'$, $y' = Y'/S'$, $z' = Z'/S'$, $x' = 0.0750 - x'$, $y' = y' - 0.5000$.
 T or $R = (-1.13751 X' + 1.00000 Y' + 0.78431 Z') 10^{-4}$.

* Temperatures correspond to values of C_2 as follows:

$cm.^{\circ}$	$^{\circ}K$.	$^{\circ}K$.
1.432	2,355	2,842
1.433	2,357	2,844
1.434	2,358	2,846
1.435	2,360	2,848
1.436	2,362	2,850

TABLE 46.—TRILINEAR CO-ORDINATES OF
SPECTRUM LOCUS
(BRECKENRIDGE AND SCHAUB)

$\lambda = 770 \text{ } M\mu \text{ at}$ $x' = 0, y' = 0.$			Wave length ($M\mu$).	$\lambda = 770 \text{ } M\mu \text{ at}$ $x'' = 0.0750, y'' = -0.5000.$		
x' .	y' .	z' .		x'' .	y'' .	z'' .
0.4500	0.5000	0.0500	380	- 0.3750	0.0000	1.3750
.4503	.5005	.0491	390	- .3753	.0005	1.3748
.4507	.5015	.0478	400	- .3757	.0015	1.3742
.4509	.5030	.0461	410	- .3759	.0030	1.3729
.4504	.5058	.0438	420	- .3754	.0058	1.3696
.4463	.5129	.0408	430	- .3713	.0129	1.3584
.4371	.5259	.0370	440	- .3621	.0259	1.3362
.4225	.5470	.0305	450	- .3475	.0470	1.3005
.3987	.5789	.0224	460	- .3237	.0789	1.2448
.3500	.6256	.0244	470	- .2750	.1256	1.1494
.2570	.6862	.0568	480	- .1820	.1862	.9958
.1477	.7343	.1180	490	- .0727	.2343	.8384
.0687	.7500	.1813	500	.0063	.2500	.7437
.0281	.7411	.2309	510	.0469	.2411	.7121
.0102	.7154	.2744	520	.0648	.2154	.7298
.0045	.6818	.3136	530	.0705	.1818	.7477
.0020	.6462	.3518	540	.0730	.1462	.7808
.0008	.6058	.3934	550	.0742	.1058	.8200
.0004	.5572	.4425	560	.0746	.0572	.8682
.0002	.4979	.5019	570	.0748	-.0021	.9273
.0002	.4265	.5733	580	.0748	-.0735	.9987
.0001	.3441	.6558	590	.0749	-.1559	1.0810
.0001	.2588	.7411	600	.0749	-.2412	1.1663
.0001	.1811	.8189	610	.0749	-.3189	1.2440
	.1211	.8790	620	.0750	-.3790	1.3040
	.0783	.9216	630	.0750	-.4217	1.3467
	.0473	.9527	640	.0750	-.4527	1.3777
	.0267	.9733	650	.0750	-.4733	1.3983
	.0146	.9854	660	.0750	-.4854	1.4104
	.0084	.9916	670	.0750	-.4916	1.4166
	.0040	.9960	680	.0750	-.4960	1.4210
	.0009	.9991	690	.0750	-.4991	1.4241
		1.0000	700	.0750	-.5000	1.4250
		1.0000	710	.0750	-.5000	1.4250
		1.0000	720	.0750	-.5000	1.4250
		1.0000	730	.0750	-.5000	1.4250
		1.0000	740	.0750	-.5000	1.4250
		1.0000	750	.0750	-.5000	1.4250
		1.0000	760	.0750	-.5000	1.4250
		1.0000	770	.0750	-.5000	1.4250

Transformation equations for transforming trilinear co-ordinates—

(c) I.C.I. into R.U.C.S.:

$$x' = \frac{0.82303 x + 0.82303 y - 0.82303}{1.00000 x - 7.05336 y - 1.64023}$$

$$y' = \frac{3.69700 x - 5.07713 y - 1.36896}{1.00000 x - 7.05336 y - 1.64023}$$

(c)

TABLE 47.—THIRTY SELECTED ORDINATES FOR COMPUTING
R.U.C.S. CO-ORDINATES—PLANCKIAN SOURCE AT
2,842° K. ($C_2=1.432$ CM.[°])
(BRECKENRIDGE AND SCHAUB)

Ordinate No.	$\lambda\bar{x}'$.	$\lambda\bar{y}'$.	$\lambda\bar{z}'$.
1	415.429	440.155	507.166
*2	423.874	463.850	524.684
3	428.419	482.711	534.516
4	431.931	497.275	542.072
*5	434.970	506.632	548.431
6	437.725	513.280	554.001
7	440.287	518.569	559.009
*8	442.712	523.116	563.595
9	445.040	527.217	567.853
10	447.300	531.014	572.402
*11	449.498	534.598	575.650
12	451.635	538.022	579.282
13	453.724	541.331	582.783
*14	455.782	544.555	586.186
15	457.818	547.719	589.514
16	459.844	550.844	592.787
*17	461.872	553.948	596.029
18	463.922	557.051	599.266
19	466.038	560.174	602.517
*20	468.250	562.339	605.812
21	470.591	566.573	609.181
22	473.103	569.911	612.660
*23	475.844	573.390	616.298
24	478.900	577.072	620.166
25	482.393	581.033	624.376
*26	486.543	585.404	629.118
27	491.662	590.415	634.631
28	498.277	596.490	641.398
*29	507.391	604.693	650.722
30	525.695	619.580	668.621
Factors.	$F\bar{x}'$.	$F\bar{y}'$.	$F\bar{z}'$.
30 ordinates	0.0011887	0.0177684	0.0215693
*10 ordinates	0.0035660	0.0533053	0.0647080

Let $X' = F\bar{x}'\Sigma T_{\Lambda}$, $Y' = F\bar{y}'\Sigma T_{\Lambda}$, $Z' = F\bar{z}'\Sigma T_{\Lambda}$.
 $S' = X' + Y' + Z'$, $x' = X'/S'$, $y' = Y'/S'$, $z' = Z'/S'$.
 $x'' = 0.0750 - x'$, $y'' = y' - 0.5000$.
 T or $R = (-1.13751 X' + 1.00000 Y' + 0.78431 Z') 10^{-6}$.

(d) R.U.C.S. into I.C.I.:

$$x = \frac{+0.06325 x' - 0.34073 y' + 0.25264}{+1.00000 x' - 0.31564 y' + 0.34389} \quad (d)$$

$$y = \frac{-0.22358 x' + 0.02509 y' + 0.09124}{+1.00000 x' - 0.31564 y' + 0.34389}$$

(e) Luminosity coefficients for R.U.C.S. system:

$$L_{x'} = 0.13857, L_{y'} = -0.12182, L_{z'} = -0.09554.$$

(f) Luminosity coefficients adjusted to make $L_{y'}$ equal unity:

$$L_{x'} = -1.13751, L_{y'} = 1.00000, L_{z'} = 0.78431.$$

(g) Trilinear co-ordinates of important illuminants:

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Source	x''	y''
Blackbody at*:		
1,000° K.	0.0743	-0.2931
1,500° K.	0.0704	-0.1859
1,900° K.	0.0644	-0.1325
2,360° K.	0.0557	-0.0912
2,848° K.	0.0457	-0.0616
3,500° K.	0.0328	-0.0351
4,800° K.	0.0115	-0.0053
6,500° K.	-0.0078	0.0135
10,000° K.	-0.0296	0.0291
24,000° K.	-0.0530	0.0416
∞	-0.0668	0.0475
Equal Energy	0.0000	0.0000
I.C.I. Illuminant A	0.0457	-0.0616
I.C.I. Illuminant B	0.0096	-0.0053
I.C.I. Illuminant C	-0.0113	0.0134

* $C_2 = 1.435 \text{ cm.}^\circ$

The C.I.E system of measuring colour may be explained to the non-technical reader perhaps more clearly by reference to a diagram by

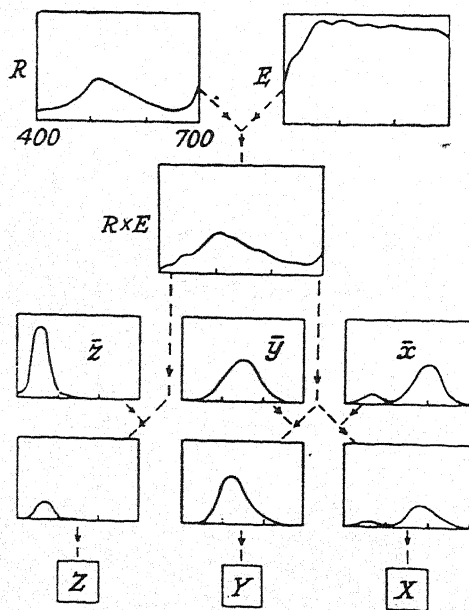


FIG. 131.—Diagrammatic representation of a method for computing the tristimulus values X, Y and Z. (D. L. MacAdam.)

D. L. MacAdam illustrating his well-known paper "Fundamentals of Color Measurement" (Fig. 131). The curve in the upper left corner of the diagram represents the spectral reflectance of a green object for every wavelength of the visible spectrum from violet on the left to red on

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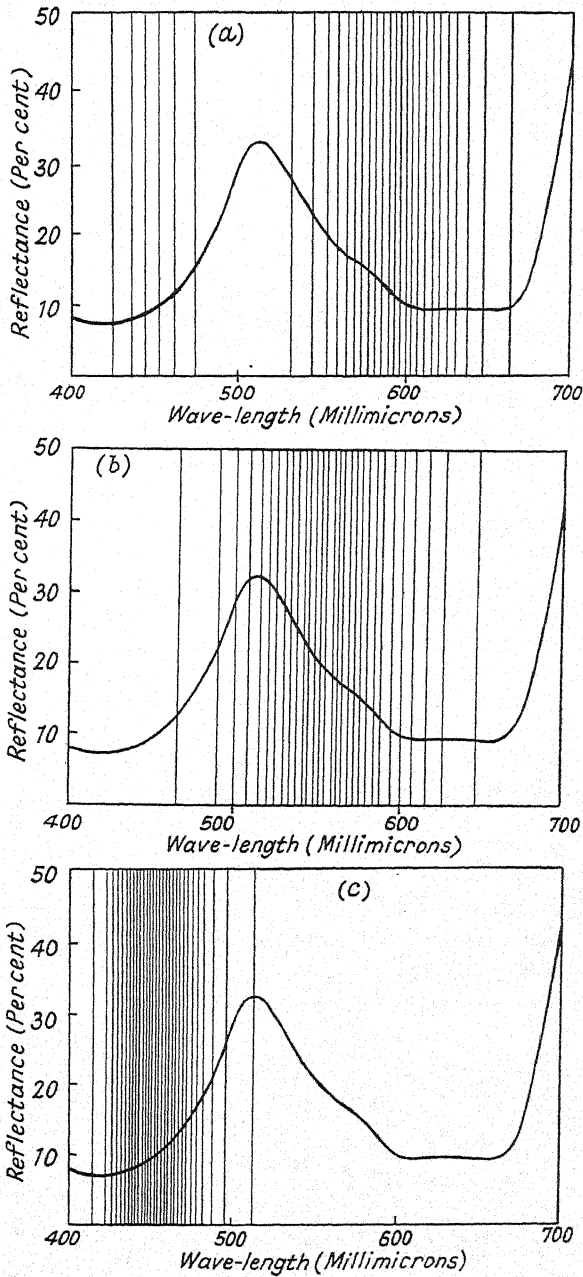


FIG. 132.—Selected Ordinate method of computing tristimulus values; (upper) X, (centre) Y, (lower) Z. (D. L. MacAdam.)

the right. This is known as a spectrophotometric curve. The curve in the upper right corner represents the distribution of energy of Illuminant C. The energy reflectance of the sample in this illuminant at a given wavelength is the product of the values at that wavelength indicated by the upper two curves. The product of these is shown in the curve below. The three colour-mixture functions adopted by the International Commission on Illumination are represented by the curves \bar{x} , \bar{y} , \bar{z} . Light of each wavelength reflected from the sample contributes to each primary of the colour specification an intensity proportional to the product of the energy and the corresponding function. The three curves resulting from these multiplications throughout the visible spectrum are shown in the bottom three curves. The areas under these curves are the totals of the contributions of every wavelength throughout the visible spectrum of the intensities X, Y, Z of the standard primaries necessary to match the sample.

Another and more rapid method of computing the tristimulus values has been devised. This is known as the selected-ordinate method and consists in averaging the values that the reflectance curve of each sample attains at certain wavelengths, which have been published. The thirty vertical lines in Fig. 132 are drawn at the wavelengths at which the reflectances should be read from the curve of the sample, and averaged in order to compute the tristimulus value X. The values of the reflectance at the wavelengths indicated by the vertical lines in Fig. 132 (b) should be averaged in order to compute the tristimulus value Y. Finally, the values read from the curve of the sample of the wavelengths shown in Fig. 132 (c) should be averaged to compute the tristimulus value Z. Transparent templates, on which lines are ruled corresponding to the vertical lines in Figs. 132, (a), (b), and (c), can be prepared, to be placed temporarily over the spectrophotometric curve drawn to a standard wavelength scale, as aids to calculation. The three sets of wavelengths have been derived from the colour-mixture functions adopted by the International Commission and shown in Fig. 55, and from the energy distribution of the light-source.

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Summary

By this time the reader may have some idea of the complex process of transformation which must be carried from stage to stage with the minimum of loss (see page 45). It is very wonderful that the reproduction image focused upon the retina bears as close a resemblance as it does to that image which it would have received from the original, especially when we consider that distortion can so easily occur at any stage in the process (Figs. 10 and 113). There must be a competent specialist in control at each stage in the recording and reproduction sequence. Consider the following recapitulation¹:

1. The right subject matter must be chosen for photography. In the studio there must be controlled selection of pigments, make-up, textures, found by experiment to reproduce consistently.
2. Suitable illumination must be used; its spectral energy distribution well understood relative to the sensitivity of the film and the transmission of the filters. Its distribution must be such as to avoid undue contrasts of luminance, its intensity sufficient to expose fully the negatives.

¹ In this sequence paragraphs numbered 2 to 6 inclusive do not apply to analysis by integral layer materials such as Kodachrome, Ansco Color, Agfacolor, etc.

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3. The highest-speed, finest-grain, panchromatic emulsion must be chosen to record the colour analysis; as even in its response to the visible spectrum as it can be made. This is available now.
4. Correctly balanced analysis filters must be used such as to record identical densities for all steps of the grey scale.
5. A beam-splitting system must be used for the camera, capable of providing two geometrically identical images, parallax free and of identical magnification. The finest colour-corrected objective is essential; the images to be preferably of normal dimensions.
6. The negative or negatives must be developed in a fine-grain developer to a gamma of, say, 0.65. If the negatives are on separate films, then they should be developed to different times to compensate for the colour gamma effect, in order that their gamma should be identical.
7. A subtractive printing process must be chosen which is capable of registering every gradation in the negative for each subtractive primary. The subtractive colours must be as nearly theoretically correct as it is possible to obtain—magenta, yellow, and cyan. The colours must be reasonably fast to light and as transparent as possible. The balance of the three printings must be such as to yield a perfectly neutral grey scale. The printing must be consistent. The sound reproduction should be equal to normal black and white. These conditions should be inherent characteristics of the material and are largely met by the manufacturer in the case of integral layer films such as Kodachrome, Ansco Color, Agfacolor, or Ektachrome.
8. So far we have hypothesized a subtractive process. There is, however, one practical additive process, Dufaycolor. Conditions 4 and 5 are eliminated, except in so far as the objective is concerned. Balance of trichromatic printing must be obtained by careful grading.
9. The film must be projected with as neutral a white light as we can obtain with existing carbons, the spectrum of the source of light having no marked dominant hue and an unbroken wavelength range.
10. The screen illumination for the white part of the picture should not fall below 10 foot-candles. The screen must be as perfect a white as we can get, having no selective absorption and possessing the maximum reflection power.
11. The eye of the observer will, we hope, be normal in its response to colour.

When approached by people who state that they are the owners of the world rights of a perfect three-colour process, if sufficiently impressed

by a demonstration reel and desirous of giving the process a practical test, the following trials of the system are suggested:

1. A perfectly neutral grey set must be reproduced. Black, grey, and white costume. In fact, black, white, and grey everywhere except the flesh of the actor. If the set is photographed minus actors, when it is projected it should be practically indistinguishable from a black-and-white film. This condition is very difficult indeed to fulfil.
2. No fringing whatever must be visible, even on closest inspection. Such fringing as occurs is due to faulty registration in printing, unequal size of images, parallax, etc.
3. Adequate exposure must be obtained with less than three times the illumination brightness normally used.
4. A *lemon*-yellow band should be painted on a white background and photographed. The lemon yellow should be accurately reproduced. Against a neutral grey background photograph a band of vivid emerald green; ditto with violet, ultramarine blue, magenta, cerise pink, olive green, turquoise blue. Note the reproduction of these.
5. Finally, photograph a close-up of a face with *no make-up*, and inspect the reproduction of that particular complexion.
6. Photograph a draped curtain of some desaturated colour such as pale blue. Take 100 ft. of film and examine the print for variation, flushing, and steadiness generally.
7. For a rough resolving power test, photograph a newspaper so as just to fill the frame, and see how much you can read on the screen and also how much can be read through a magnifying-glass when the film is inspected in the hand.
8. Photograph a dozen of the studio staff standing 30 ft. away from the camera using a 40-mm. lens, and see whether you can recognize them individually on the screen.

Two-Colour Cinematography

If reproduction of nature is attempted with two colours only, our choice is determined by practical considerations, and certain compromises must be made.

That a representation of nature in two colours only is acceptable to the eye is due to the fact that pairs of hues—namely, two visual stimuli differing in spectral distribution—may be chosen which, when added, produce the sensation white (see table of complementaries¹), or which,

¹ Complementary pairs of colours are defined as those which when combined produce a mixture-colour matching some agreed-upon neutral or achromatic colour. Pairs of different samples of light which produce an achromatic stimulus when

when constituting the transmittances of transparent substances and subtracted from each other, completely absorb each other's transmitted light. No pair will be of much use unless we can obtain black and grey (therefore a complementary pair), and of possible pairs red-orange and green-blue is the only one suitable, since it is evident that it would not be possible to represent an approximation to the general appearance of nature with any other pair—as, for example, yellow-orange and blue-green, or yellow-green and blue-violet, though such pairs are quite capable of giving perfect greys and blacks. And the same applies to a pair such as magenta and green. It is essential to represent, with some semblance to truth, the sky, and flesh, and foliage. This means that we *must* choose red-orange and green-blue. The records must be the complementaries of these reproduction hues; therefore the negatives must be recorded through filters which respectively absorb these two regions, or which in any case absorb radiant energies which are capable of stimulating these two colour sensations.

But it is impracticable to use recording filters which are truly complementary, for the following reasons.

Consider the reproduction of pure blue-violet and also of violet. The transmission of a filter which is complementary to red-orange would necessarily transmit the remainder of the spectrum—namely, everything from yellow to violet (this is a green-blue such as Wratten No. 43). Now, a negative exposed behind such a filter would record density for all wavelengths, say, from 580 M_μ to 400 M_μ . Transparencies on this negative represent values to be printed in the colour of the light *not* recorded by the negative—viz., red-orange, or minus green-blue. Therefore no red-orange is printed for the region 580 M_μ to 400 M_μ . Similarly, the red-orange filter records density for all wavelengths from 700 M_μ to 580 M_μ . Transparencies on this negative represent values to be printed in the colour of the light it did *not* record—viz., green-blue (minus red-orange). Therefore no green-blue is printed for the region 700 M_μ to 580 M_μ ; but full green-blue *is* printed from 580 M_μ to 400 M_μ , and we have observed above that *no* red-orange is printed here. Hence deep blues and violets of 490 M_μ to 400 M_μ are represented in the synthesis as pure green-blue, which is a very unsatisfactory effect. For this reason a filter is chosen which does not record between 450 M_μ and 400 M_μ . Therefore this region is printed in red-orange. It is also printed in green-blue (see above), so that the region 460 M_μ to 400 M_μ is synthesized by green-blue and red-orange superposed—or *black*; a better effect than green-blue, as the psychological effect is not unlike that of a deep blue.

combined in suitable proportions are said to have *complementary chromaticities*. Samples of light which have complementary chromaticities and also the proper amounts of luminous flux to produce an achromatic mixture are said to have complementary colours. (See Table 69, page 638.)

Consider the reproduction of the spectrum:

<i>Red-Orange Record.</i>		<i>Green-Blue Record.</i>	
Red	} Density Recorded	Red	} Printed in Red-Orange
Orange		Orange	
Yellow		Yellow	
Green	} Printed in Green-Blue	Green	} Density Recorded
Blue-Green		Blue-Green	
Blue		Blue	
Blue-Violet		Blue-Violet	
Violet		Violet	

The superposed subtractive synthesis would then be:

Red	} Red Orange
Orange	
Yellow	
Green	} Blue-Green
Blue-Green	
Blue	
Blue-Violet	
Violet	

A satisfactory compromise is to use a green-blue filter which does not transmit blue-violet or violet, thus:

<i>Red-Orange Record.</i>		<i>Green-Blue Record.</i>	
Red	} Density Recorded	Red	} Printed in Red-Orange
Orange		Orange	
Yellow		Yellow	
Green	} Printed in Green-Blue	Green	} Density Recorded
Blue-Green		Blue-Green	
Blue		Blue	
Blue-Violet		Blue-Violet	
Violet		Violet	} Printed in Red-Orange

The reproduction of the spectrum would then be:

Red	} Red-Orange
Orange	
Yellow	
Green	} Green-Blue
Blue-Green	
Blue	
Blue-Violet	} Red-Orange minus Blue-Green: or <i>Black</i>
Violet	

The reproduction of the spectrum is, of course, only of theoretical interest. We know that orange and yellow objects reflect green light in abundance. Therefore these objects will record through both filters. The recording of the principal hues as ordinarily occurring in nature is therefore:

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Red	Red-Orange	}	Green-Blue
Orange			
Yellow			
Green			
Blue-Green	Black	}	
Blue			
Blue-Violet			
Violet			

Hence the yellow region will be reproduced with equal quantities of minus red-orange and minus green-blue—or grey. This is not very satisfactory, since yellow is important in flesh tones. We cannot possibly obtain a yellow by any mixture of red-orange and green-blue, but we can represent yellow by a pale red-orange (*e.g.*, a pale salmon pink). This is accomplished by arranging for the two filters to have the same transmission at a point somewhat further in the green region rather than at the yellow part of the spectrum. It is found that a green of about 575 $M\mu$ is best chosen as the part of the spectrum to be reproduced as grey. This is the case if we make use of filters such as Wratten Nos. 28 and 40A recommended for two-colour recording with high-intensity tungsten lamps as the light-source (Table 48).

The total range of colours obtainable from a pair of complementaries is found in a cross-section of the "colour solid" (a construction consisting of two pyramids base to base, having two sides curved and bulging somewhat irregularly). Such a section will consist roughly of two triangles base to base (Fig. 139).

TABLE 48

Wave-length in $M\mu$.	Wratten Filter No. 28 (Red-Orange).	Wratten Filter No. 40A (Green-Blue).	Wave-length in $M\mu$.	Wratten Filter No. 28 (Red-Orange).	Wratten Filter No. 40A (Green-Blue).
400			560	0.38	36.1
10			70	2.40	22.9
20			80	10.9	11.3
30			90	31.5	5.00
40			600	54.8	1.95
50			10	70.5	0.71
60		5.24	20	80.0	0.28
70		27.6	30	83.5	0.10
80		54.9	40	85.5	
90		66.0	50	86.7	
500		72.5	60	87.5	
10		73.0	70	87.8	
20		71.8	80	88.0	1.97
30		66.0	90	88.0	7.95
40	0.10	60.0	700	88.0	15.7
50	0.17	50.6			

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The Wratten Filters 28 and 40A have the following chromaticity co-ordinates in Illuminant C. Dominant wavelength and excitation purity are also given:

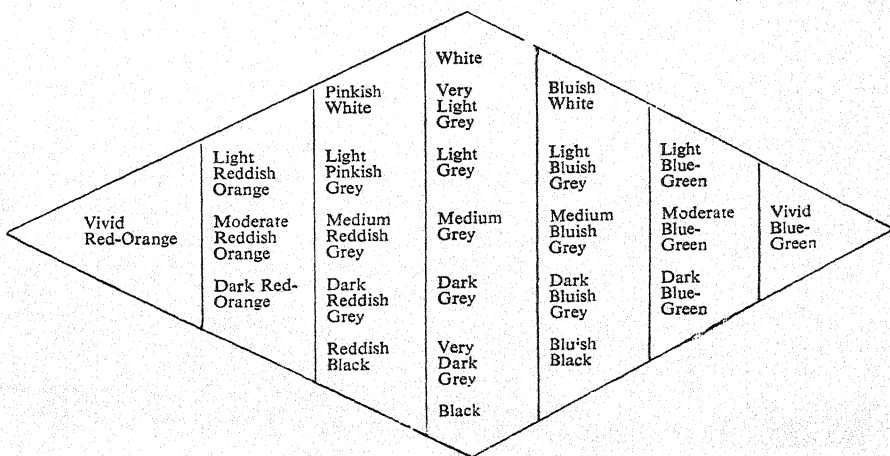
<i>Wratten Filter.</i>	<i>x.</i>	<i>y.</i>	<i>(M_μ).</i>	<i>P</i> <i>(%)</i> .
No. 28	0.6635	0.3363	609.4	100.0
No. 40	0.1882	0.5366	514.7	44.6

This is another way of stating that we can obtain every degree of desaturation of each of these hues and every degree of lightness. The range may be diagrammatically represented, but the diagram has no real significance in so far as the relative position of the colours shown below is concerned.

Table 49 indicates how the principal colours are reproduced in a two-colour process:

TABLE 49

<i>Colour of Original.</i>				<i>Colour Reproduced.</i>			
White	White		
Grey	Grey		
Black	Black		
Red	Red-Orange		
Orange	Light Red-Orange		
Yellow	Very Pale Orange (Pinkish)		
Yellow-Green	Grey		
Green	Grey Green-Blue		
Blue-Green	Green-Blue		
Blue	Deep Green-Blue		
Blue-Violet	Blackish Green-Blue		
Violet	Black		
Purple	Reddish Grey		
Rose	Grey Red-Orange		
Flesh Colour	Fairly correct (tones of Salmon Pink)		
Foliage	Grey Bluish Green		
Sky-Blue	Pale Blue-Green		



The table shows why, in two-colour processes such as the earlier Technicolor, and to some extent in the new "Technichrome," there was such an insistence upon a curious salmon, or coral, pinkish orange, and in contrast to it tones of greenish blue.

In order to recover the missing yellow, some workers have dyed the whole film yellow or used a yellow-dyed base for the positive film, but this trick involves the sacrifice of most of the blues, since yellow is the subtractor for blue (minus blue *is* yellow).

In Hamburger's "Polychromide" process the two colours were each mixed from a pair. For instance, the red-orange was a mixture of magenta and auramine (yellow). Hamburger held that the auramine had some mysterious sympathy for the parts of the image corresponding to yellow in the original. This was absurd, but there was an unquestionable tendency for the lighter tones to be reproduced as pale gold, or at times even as yellow—and this effect was due to the fact that in the clearing-bath, which followed the chromium bleach mordant, the magenta was removed more quickly than the auramine, with the result that the lighter densities of silver dyed with this mixture were very nearly free of the magenta component. Exactly the same principles applied to the green-blue, which he mixed with malachite green and a deep purple-blue dye.¹ This species of dichroic effect can be made good use of in two-colour processes to camouflage their shortcomings. Hamburger claimed to reproduce foliage as green, and the sky as a purplish blue; and some prints which the writer has seen nearly substantiate his claims.

Two-Colour Analysis and Subtractive Synthesis

The methods of recording are discussed elsewhere. Perhaps the simplest method is to use a bipack, and this has been used far more frequently than beam-splitting. On the other hand, the beam-splitter is the only means by which quite perfect negatives can be made. If the synthesis is to be by some subtractive system of printing, full-sized images should be recorded. Suitable cameras have been made by Technicolor, Dufay-Chromex (Coote), Hamburger, Brewster, etc. The Cinecolor (British) and Raycol type of beam-splitting prism system, in which pairs of small negatives occupy the area of a normal frame, could probably be designed to take two full-sized pictures, but such systems have the disadvantage of requiring two or more lenses. Focusing is delicate and change of focal length of the lenses is extremely difficult. Each focal length generally involves a separate prism divider. Printing from a single film carrying full-sized pairs of records necessitates an optical printer by which *every other* negative image can be successively printed on one side of a double-coated film. Thus the negative printing gate of the optical printer moves the film two frames to one of the

¹ Helio Safranine.

positive gate, so that only alternate frames are printed, the other frames being skipped. Kelley designed a skipping contact step-by-step printing machine which eliminated the necessity for the slow-working optical printer, while at the same time definition was improved.

On the other hand, bipack negatives can be printed contact on to either side of double-coated film. The only requirement is that the printer should have pilot pins which ought to be reversible, so that when the positive film is turned over for printing the other side the full-fitting pilot pin always engages the same perforations.

Debrie made a very good contact step-by-step printing machine based upon a patent of Hamburger, in which the double-coated positive film is sandwiched between the two negatives. Both sides of the film can be printed simultaneously, there being two light-sources which are independently controlled by the usual Debrie light-change mechanism. Multicolor imitated this type of printing machine.

"Duplex" printers with pairs of gates side by side are used today for printing Trucolor at the laboratories of Consolidated Film Industries.

Additive Two-Colour Synthesis

From a colorimetric point of view, the colour resulting from the combination of two kinds of light—for instance, the colour of the light reflected by a surface illuminated simultaneously by two sources—has tristimulus values which are the sums of the corresponding tristimulus values of the two colours which are produced by the separate action of each of the constituent lights. If the tristimulus values of the colour produced by one of the component lights are represented by X_1, Y_1, Z_1 , and if the tristimulus values of the colour produced by the other component are X_2, Y_2, Z_2 , then the colour produced by the combined action of the two lights is specified by the tristimulus values:

$$X = X_1 + X_2, \quad (1)$$

$$Y = Y_1 + Y_2, \quad (2)$$

$$Z = Z_1 + Z_2. \quad (3)$$

The corresponding chromaticities are represented by the co-ordinates (X_1, Y_1) , (X_2, Y_2) , and (X, Y) . It can be shown that the point representing the mixture is the centroid of the two points (Fig. 133) representing the components, these points being weighted with the sums of the corresponding tristimulus values:

$$x = (x_1 m_1 + x_2 m_2) / (m_1 + m_2), \quad (4)$$

$$y = (y_1 m_1 + y_2 m_2) / (m_1 + m_2), \quad (5)$$

where

$$m_1 = X_1 + Y_1 + Z_1 \quad (6)$$

and

$$m_2 = X_2 + Y_2 + Z_2. \quad (7)$$

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Similarly, the point representing the chromaticity produced by the mixture of any number of component lights can be shown to be the centroid of the points representing the constituents, each of these points being weighted by the sum of the tristimulus values of the corresponding constituent. Therefore the point representing the mixture must lie on the straight line between the points representing the constituents, and the chromaticity of any sample of light is the centroid of the points representing all the spectral components. All spectral components

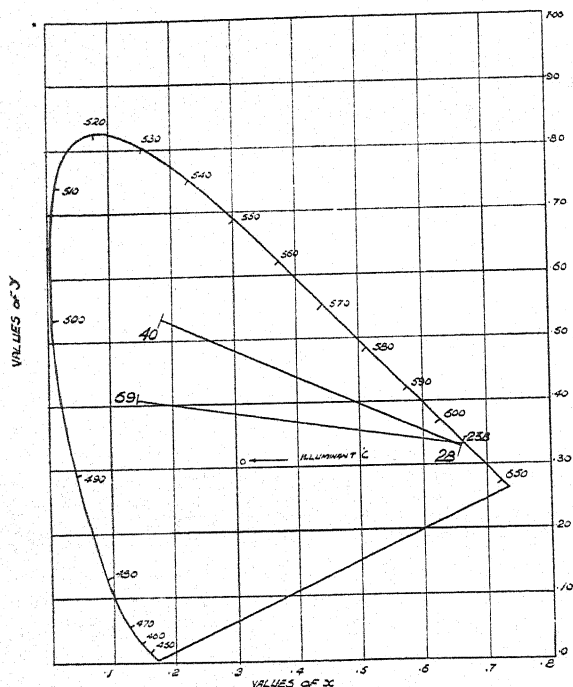


FIG. 133.—Chromaticities of certain pairs of Wratten filters for two-colour additive analysis.

are represented on the curved locus of the C.I.E. (I.C.I.) diagram; therefore the centroid representing any colour must lie within the area enclosed by the spectrum locus and the straight line connecting its extremities. This area therefore represents the total extent of physically realizable chromaticities.

Additive two-colour synthesis is capable of a remarkably close approximation to the appearance of nature. Although there is a total absence of genuine yellow, yellow-green, blue-violet, purple, magenta, rose, pink, and all desaturations of these hues, nevertheless, by a partly psychological process, these colours often appear to be present in the

picture, perhaps owing to our expectation that certain colours are associated with certain objects. One has seen a field of daffodils reproduced convincingly, yet there can have been no pure yellow on the screen. The same phenomenon is seen with many other colours. By some magic of simultaneous contrast blonde hair will seem blonde when it is really rendered as a pale greyish orange; grey-blue-green leaves look yellow-green and browns masquerade as violet.

But the full wonder of simultaneous contrast is revealed in the device of substituting the unfiltered light of the arc for the green-blue filter. This was invented by William Fox and William Harrison Hickey and Kinemacolor of America in the earliest days of colour films. It was later "re-invented" by A. Bernardi for Raycol, who probably discovered the effect accidentally. In any case, it is surprising how much can be obtained if one picture be projected through a red-orange filter and the other with *no filter whatsoever*. Under these conditions we can consider one of the two additives as a desaturated blue-violet (bluish white), because this is the appearance of the radiation of a cerium-cored carbon arc (high intensity). This blue-white will occur throughout the picture in proportion to the presence of green-blue light in the original subject. By means of simultaneous contrast with the various tints and shades of red-orange, the apparent saturation of the blue-violet becomes very much intensified. The writer has seen pictures thus projected in which bluebells have assumed their normal hue, and a pale blue dress was admirably reproduced. The general colour effect is dignified, restrained, and very pleasant to look upon. The mind overlooks, somehow, the numberless inaccuracies which must be inevitable (see page 266).

It would be easy to apply the same principle to the subtractive synthesis. The silver image printed on one side of double-coated stock would have to be dye-toned, or metal-toned, or colour-developed red-orange; while the other side would have upon it a normal black-and-white image which had been left unchanged after normal processing.

When the synthesis of a two-colour process is additive, the question of the heat to which the projection filters are subjected becomes serious. In the Raycol process it will be recalled that a split projection lens was used. This unit consisted of two projection lenses of, say, $2\frac{1}{2}$ -in. focus, which had each had about one-third of the lens cut off. By this means the centres, or axes, of the lenses were brought close enough together to correspond to the separation of the axes of the two little pictures (say $7\frac{1}{2}$ mm.) occupying the area of one normal frame. The only place for a filter is immediately in front of the lens. Gelatine filters in this position rapidly deteriorate, but there are coloured glasses available whose absorption characteristics are close to the theoretical two-colour additive primaries. A selenium glass is suitable for the red-orange, and an iron and copper glass (Chance's "Calorex") has the requisite absorbance

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of red and transmittance of green and blue. To-day the problem is solved by heat-absorbing glasses possessing little selective absorption in the visible region, such as Chance's ON 20. A piece of ON 20 glass 3 mm. thick will absorb at least 90% of the heat and transmit 87% of light.

Additive Processes

"Let there be light," said God; and forthwith light ethereal, first of things, quintessence pure, sprung from the deep; and, from her native east, to journey through the aery gloom began, sphered in a radiant cloud.—MILTON.

Involving Optical Accessories in Projection, or Special Camera Arrangements, or Both

IN additive processes of this class the primary elements are combined (viz., added to each other) upon the screen, or added as sensations received successively at such a frequency that the individual stimuli blend. Thus images may be combined simultaneously or successively. Each primary-coloured picture which is to form part of the combination must be separately projected. Each element represents correct proportions of one of the primary colours. In this category the positive film is generally black and white, although it has also been proposed to stain each separate image with its correct projection filter. In the process of C. H. Friese-Greene exhibited in 1925 the alternate frames were stained red and blue-green, thus dispensing with the rotating colour disc on the projector which persistence of vision systems require. Each positive part-picture has to be projected through a filter similar to (but generally more saturated; narrower wavelength cut) that which was used for taking the corresponding negative.

ADDITION BY SIMULTANEOUS PROJECTION

The principal disadvantages of this class of additive processes is that unless two projectors are used it is always necessary to substitute for the ordinary projection lens a special lens unit before the additive film can be projected. It is argued by enthusiasts that this is only a minor mechanical aspect, that some kind of arm can be attached to the projector head upon which the existing black-and-white lens and the special colour projection unit can both be mounted, and that it requires only to be moved over into the axis of the projection beam in order to get correct focus instantly. Nevertheless, projectionists dislike moving their lenses for quite natural reasons. In some systems it is necessary to spend considerable time in adjusting a colour lens unit in order to obtain accurate superposition of the two or more part-pictures upon the screen. The adjustment will be required in every theatre owing to local

conditions, length of throw, size of screen, and so on. Unless every theatre could be equipped with a standard colour projection unit which could be relied upon to give perfect results at all times, it is difficult to see how the sponsors of such a process could avoid spending a great deal of money on special service mechanics, who would have to make the essential trial of projection before the arrival of a colour film at a theatre. Furthermore, in the event of several different processes each endeavouring to exhibit their films at the same theatre, the projectionist would have to be something of an optical expert to effect the rapid changes of lens unit between the showing of successive films. Nevertheless, money continues to be spent on the development of additive processes, and films have been completed only for their producers to find that the task of renting them, and at the same time making certain of adequate projection, limits their exhibition to the very few theatres having managers who can be persuaded to experiment. It seems almost certain that projection troubles will inevitably bring about the extinction of additive processes, more especially now that satisfactory colour-on-film processes are available.

On the other hand, the additive processes possess the undeniable advantage of cheapness of production, since the cost is identical to black-and-white, and the projection positive is always a straight print from the negative. The part-pictures usually occupy the space of a single frame, so that no extra film is needed, and the stock used is, of course, normal fine-grain positive.

Another defect of processes of this category is loss of light in projection. In two-colour processes the luminous efficiency may fall well below 25 per cent. of the black-and-white image, and cannot possibly exceed 50 per cent. The projection lenses, when arranged in pairs, must have their centres not more than 7.5 mm. apart. Thus to obtain a reasonable aperture the lenses must be almost cut in half. The three-colour lenses are no more efficient; in these the normal aperture of the black-and-white lens is divided into three segments. The loss of light due to absorption by the colour filters is very serious, as saturated colours of narrow spectral transmissions should properly be used in order to conform to the theoretical conditions.¹ It was no doubt owing to poor illumination that in the Raycol (two-colour additive) process white light was substituted for the green-blue filter.

ADDITIVE PROCESSES: TWO-COLOUR

GENERAL REQUIREMENTS

Camera.—A pair of lenses of focal length suitable for substandard film, say of 25 mm. or 35 mm., mounted very close together, with centres at 7.5 mm. As the two pictures will have been taken from two

¹ A possible set of glasses would be Chance's OR 2 (Red), OGr 1 (Green), OB 10 (Blue).

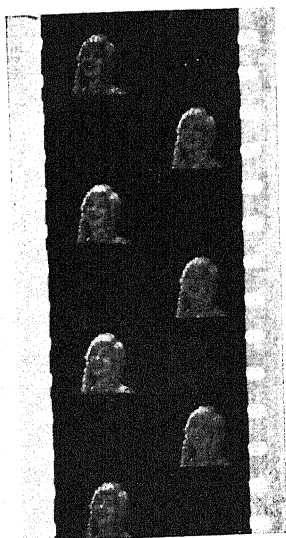


FIG. 134.—Early Raycol positive.
(Note diagonal arrangement.)

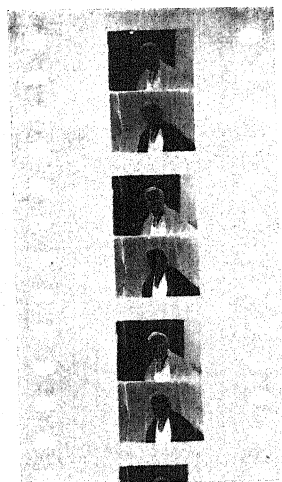


FIG. 135.—Raycol negative.
(About 1933.)

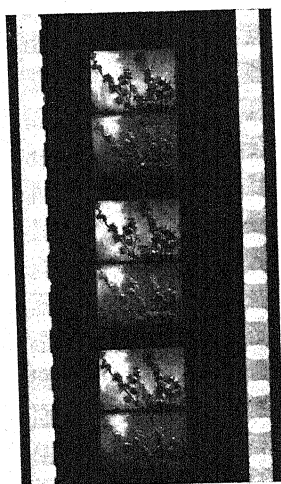
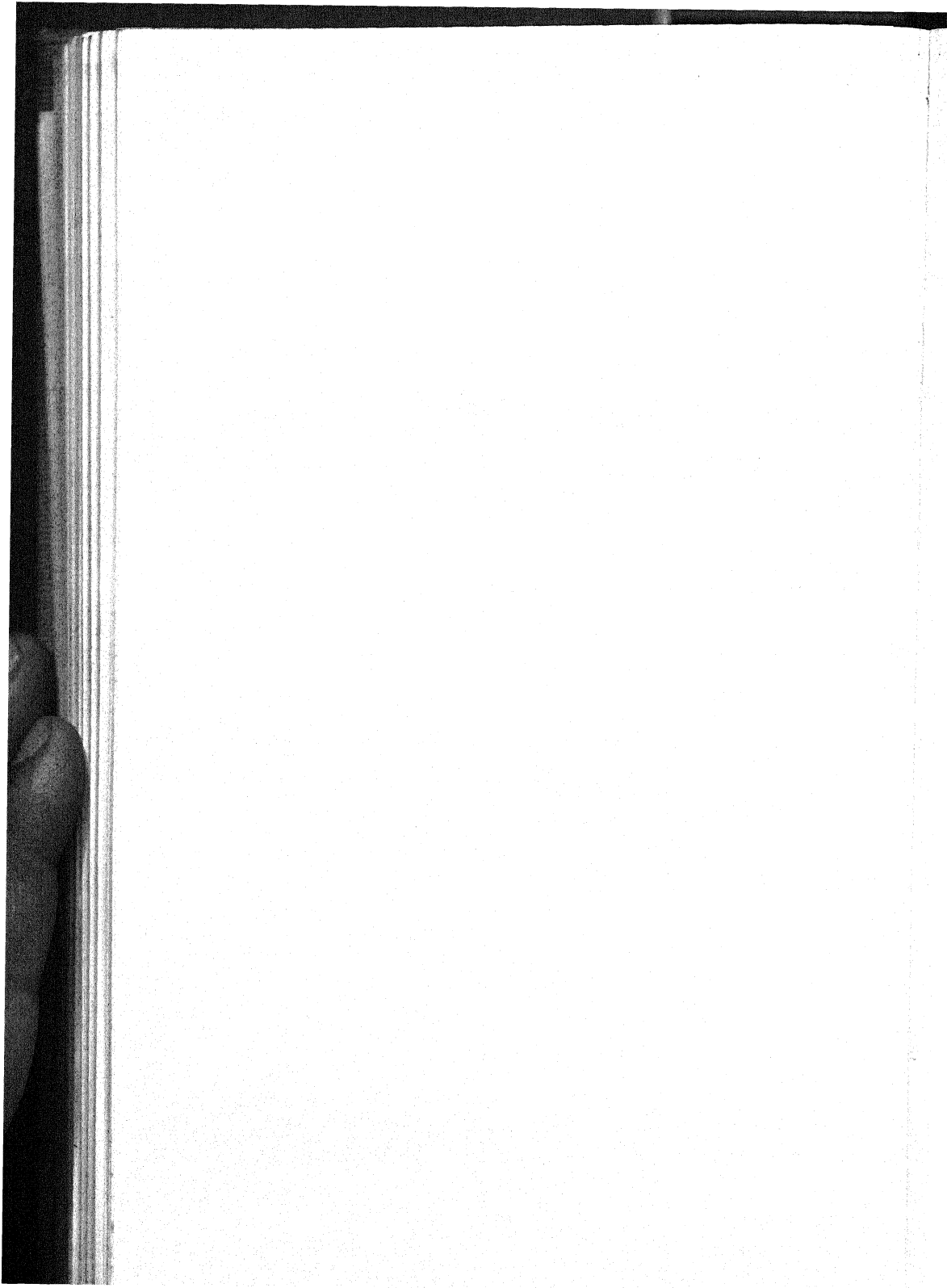


FIG. 136.—Raycol positive.



points there will be parallax fringing unless the light is split into two beams *before* reaching the lenses. This problem has been solved by more than one optical arrangement. The size of each picture is approximately 8×12 mm. The two pictures may be placed side by side, or one beneath the other within the space of one frame (16×24 mm.), or in some position on two adjoining frames provided the camera has a gate of the right dimensions. The appearance of the finished positive is normal, except that the pictures look like a print from a substandard negative on 35-mm. film. The pictures are grouped in pairs slightly separated from each other by the masking. It is important that the pictures should be carefully masked off from each other by a "septum," otherwise there is some chance of the rays overlapping into the neighbouring picture area.

Projection.—Projection is usually effected by a divided lens (in effect two lenses, as in the camera). Each half of the lens projects a complete picture in one of the two chosen colours. A red-orange filter is placed in front of one of the lenses, and a blue-green filter in front of the other. Alternatively, the blue-green filter may be omitted, and the blue part of the picture is then projected in the bluish-white light of the high-intensity projection arc. By this method surprisingly good subjective blue tones are obtainable. Mechanical or optical adjustment must be provided to move one half of the lens relative to the other in order to effect accurate registration upon the screen.

In installing a lens in a given theatre, accurate calibration has to be carried out in the first instance to ensure superposition of the pictures upon the screen.

EXAMPLES

Raycol Process. (Obsolete.)

Camera.—Operations were begun in 1928-9 with a rather elaborate prism divider placed behind a single-projection lens (Fig. 134). Various modifications were tried, but parallax was continually encountered. In 1931 the writer, in association with Messrs. Bellingham & Stanley Ltd., designed for Raycol a beam-divider incorporating a plate of Iceland spar. This was the first time that a double refracting medium had been employed as the dividing element of a beam-splitter for colour photography. Two objectives were mounted behind the prism unit. The resulting pictures were entirely free from parallax. As the light was plane polarized there was some reason to think that there was an improvement in the photographic image owing to reduction of scatter. The two pictures were disposed vertically one beneath the other on the standard frame, size each 8×12 mm., centres 7.5 mm. apart (Figs. 135 and 136). Taking filters were Wratten Filters 28 and 40A.

The optical system was mounted on a normal camera-lens turret (Fig. 137).

Projection.—A divided projection lens consisting of two sawn-off lenses. The respective half-lenses were separated by a metal spring, and means were provided for increasing or decreasing the separation of the axes of the two half-lenses in order to obtain superposition upon the screen. The colour filters were made of glass, as considerable trouble was experienced with gelatine owing to the great heat to which the filter was exposed during projection. A selenium pot glass was used for the red-orange, and a very thin piece of "signal green" copper glass for the blue-green complementary component. Originally Raycol had

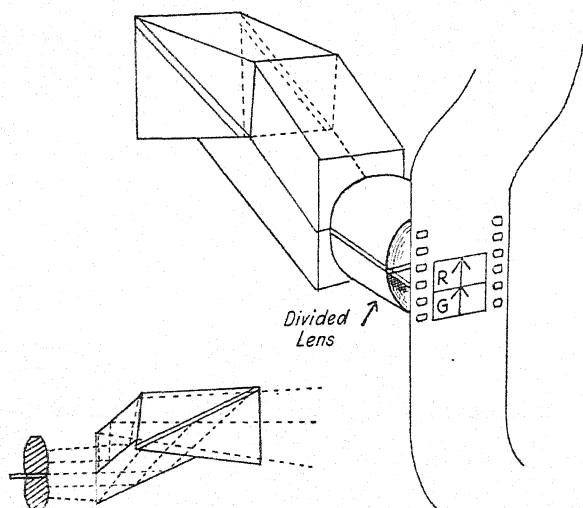


FIG. 137.—Raycol optical system (Bellingham and Stanley, E.P. 398,100, 1933).

dispensed with the blue-green glass altogether, using white light only, and a patent was obtained, although this suggestion was by no means new in the history. The effect was astonishingly good, and it is worth while considering in some detail how it comes about that a "one-colour" projection system can give a fair range of colour tones.

Consider the result in the case of an original colour which is not recorded upon either red or blue-green negatives; namely, a blue-violet. There will be transparency on either negative, hence maximum density on both positives; hence nothing will be projected, therefore blue is represented by black (Fig. 138).

Consider the reproduction of primary green. There will be no density on the red negative record and full density on the green negative; hence we have full density on the red positive and transparency on the white

projected positive (normally projected in blue-green); therefore green is reproduced as *white*. Desaturated greens must reproduce as more or less warm greys if light, and cold greys if dark. Thus only red is objectively reproduced with any approximation to truth, the remaining colours being reproduced as various degrees of reddish grey, neutral

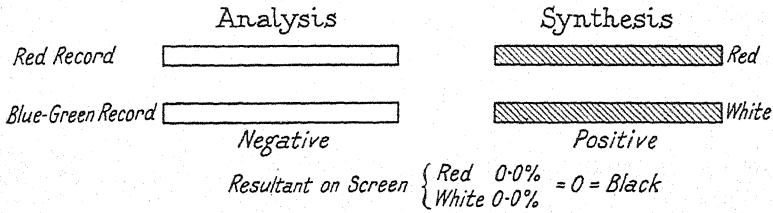


FIG. 138.

grey, or subjectively bluish grey. Yellow will be red plus white—a pink. White must necessarily turn out a light pink. By simultaneous contrast with the warm tone of reddish grey, the tones which are minus red will appear singularly blue, especially in the higher lightnesses. These portions of the picture really consist of the light of the arc projected through a greater or less density of silver in the film. By the laws of

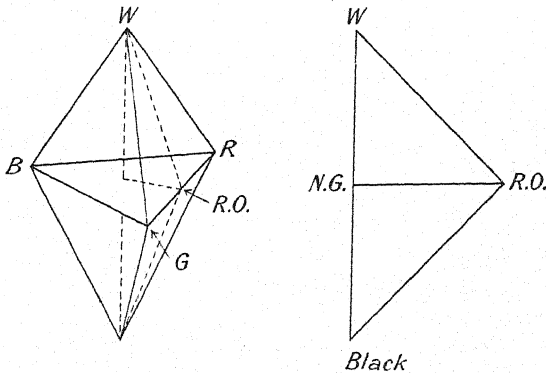


FIG. 139.

contrast they tend to appear a colour complementary to their neighbouring tones (in this case blue-green, which is complementary to red). The effect is further exaggerated by projection with a high-intensity arc, the light of which is a very bluish white.

The total range of colour obtainable in such a system can be represented in one triangular section of a pyramidal colour solid (Fig. 139) bounded by white, red-orange, and black, which means that the spectrum would be reproduced approximately thus:

TABLE 50

Hue.					Reproduction.		
Red	..	..	..	..	Red	100	White 0
Red-Orange	..	..	..	..	Red	100	White 25
Orange	..	..	..	..	Red	100	White 50
Yellow-Orange	..	..	..	..	Red	100	White 75
Yellow	..	..	..	..	Red	100	White 100
Yellow-Green	..	..	..	..	Red	20	White 100
Green	..	..	..	..			White 100
Blue-Green	..	..	..	..			White 75 (Grey)
Blue	..	..	..	..			White 50 (Grey)
Blue-Violet	..	..	..	..			Black
Violet	..	..	..	..			Black

Consider the reproduction of white by additive systems such as *Raycol*. The white represents maximum transmission by both orange and white half-lenses.

Orange half transmits 22 per cent. of the incident light.

White half transmits 100 per cent. of the incident light.

The additive colour is 61 per cent. of the original light, and this 61 per cent. consists of 18 per cent. red-orange and 82 per cent. white (a pinkish white).

With a blue-green filter transmitting 60 per cent. of the light, $\frac{22}{2} + \frac{60}{2} = \frac{82}{2} = 41$ per cent. will be present on the screen. This 41 per cent. consists of 27 per cent. red and 73 per cent. blue-green. Thus the red-orange and blue-green combination would be two-thirds as bright as the red-orange and white addition, which is in its turn less than two-thirds of normal black-and-white brightness.

Thus it appears that the substitution of white for blue-green in two-colour additive systems is a device which sacrifices colour range to obtain increased screen luminance, and there is no question that a blue-green filter must give a much expanded range of hue.

References

- "The Raycol Process," *Brit. Journ. Phot.*, Colour Supp. XXIV (Nov. 1930), p. 43.
 Alldridge Patent, *Brit. Journ. Phot.*, Colour Supp. XXIV, p. 12.
 BERNARDI, A., and RAYCOL LTD., E.P. 335,310 (1929).
 ALLDRIDGE, R. S., E.P. 322,801 (1928).
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 BELLINGHAM, L., and STANLEY, F., E.P. 398,100 (1933).

Busch Process. (Obsolete.)

(Emil Busch Optical Co. Ltd., London.)

German two-colour additive process.

Camera.—The beam was divided at the half-transparent mirror surface S1 of a double prism (see Fig. 140), and the rays then passed

partly deflected and partly direct into the objectives O1 and O2. F1 and F2 were red and green filters. S2, S3, and S4 were mirror surfaces of prisms placed behind the objectives. The two pictures were brought to a focus at B1 and B2. The ray paths were identical in this system, and it was claimed to be entirely free from parallax. The images were turned sideways to the length of the film. An ingenious finder was provided by the mirror surface S3, which did not reflect the whole of the light to produce the red picture B1, but sent one-fifth thereof undiverted

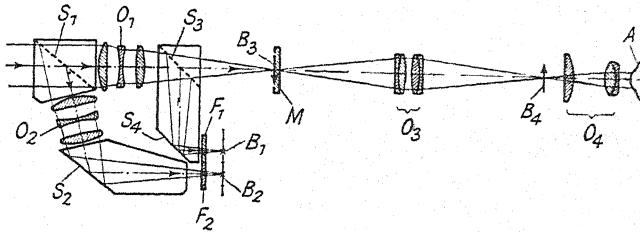


FIG. 140.

on to the ground-glass plate M and there produced an image B3, which, though weak, was light enough for observation. This was turned upright by the inverting system O3 and could be observed as image B4 through the enlarging eyepiece O4.

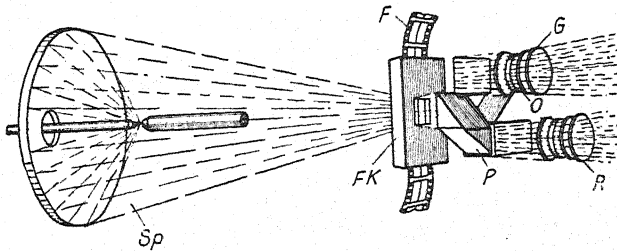


FIG. 141.

Projection.—The reproducing apparatus comprised a Busch attachment to an A.E.G projector, though this attachment could be used with other projection machines. It consisted of a double objective, the upper one of which could be adjusted by a horizontal and vertical screw to cover the part-pictures of the colour film. This objective system was mounted on the same element as the black-and-white lens, which was underneath it. By movement of a handle the change could be made from normal black-and-white to colour without delay. The projection system can be seen in Fig. 141. The illuminant was a mirror arc. The prism system increased the axis distance between the two images, and thus permitted the use of wide-aperture lenses for projection. The prism system also turned the images through 90° .

COLOUR CINEMATOGRAPHY

Remarks.—This camera (Fig. 142) and projector were designed chiefly for medical research. The prism system would not permit the use of a short-focus camera objective, and there would be insufficient illumination for commercial cinematography. It will be noticed that the arrangement of the images on the film is the same as in earlier British Cinecolor, to which the whole optical system bears a close resemblance (Fig. 143).

Morgana Process. (Obsolete.)

(The Bell and Howell Co., U.S.A.)

This was an additive process for 16-mm. film. Each successive picture frame was photographed through a red and a blue-green filter alternately. The conventional colour filter wheel was replaced by an oscillating element that brought the proper filter into position between the lens and the film at each exposure. (Note the similarity to the oscillating filter in the Hillman camera which was claimed as original.) Normal panchromatic reversal film was used. The speed was 24 frames per second, though other speeds could be used. During projection two successive frames move forward and one backward, or in reverse, in the following order: 1-2; 1-2-3; 2-3-4; 3-4-5; etc. The result was that although the film was running at a linear speed of 24 frames ($1\frac{2}{3}$ ft.) per second, 72 frames were alternating at the aperture during the same length of time, each picture being projected three times upon the screen. This accrued projection speed eliminated colour flicker and greatly reduced colour fringing. A conventional filter wheel was rotated before the projection lens at a speed of 2,160 r.p.m.

Reference

DUBRAY, J. A., "The Morgana Process," *Journ. Soc. Mot. Pic. Eng.*, **21**, No. 5 (1933), p. 403.

Gilmore Color. (Obsolete.)

An American two-colour additive process

Camera.—Two images were taken in pairs side by side on 35-mm. film by turning the images lengthwise upon the film.

Projection.—A projector equipped with the usual two-colour additive filters had optical means for erecting the two images by means of a prism system.

Remarks.—This process seems to have had affinities with the Busch two-colour camera, and also with the Cinecolor (British) camera and projection system.

Cinecolor Process¹

(Dufay-Chromex Ltd., London.)

British two-colour additive system based upon the patents of D. Daponte, S. J. Cox, and certain patents of Adam Hilger Ltd. and J. H. Dowell. Later the patents were acquired by Dufay-Chromex Ltd. (Fig. 144).

Camera.—Beam-splitter of the type in which a prism divider is placed in front of two objectives. (For details see Chapter V.) In the earlier Cinecolour cameras the images were turned sideways with respect to the film, a pair filling one normal frame. In more recent cameras the pair of images is central to the frame and normal way up (as in Raycol and other systems), each picture being approximately 8×12 mm. in size. The prism has been very carefully corrected for refraction errors due to unequal path length of the long and short wavelengths, and there is complete freedom from parallax (see Chapter V) (Fig. 145).

Projection.—An ingenious prism erecting device was formerly used for prints made from the negative on which the images were turned sideways. Later, a pair of projection lenses was used in association with a prism system in which one element was movable, enabling one beam to be moved with respect to the other in order to obtain accurate superposition of the two images upon the screen. The colour projection optical unit is so constructed that by a single movement of an arm the change can be made immediately from normal black-and-white projection to colour. The colour filters in the projection system are made of glass, and not of gelatine, presumably to withstand the high temperatures to which a filter is subjected in an additive system of this type (Fig. 146).

Remarks.—Films which have been exhibited in England and elsewhere have demonstrated that the optical system is of a high order of precision, no parallax occurring. Accurate superposition is obtained on the screen during synthesis—always a difficult achievement in additive projection, the smallest error resulting in extremely unpleasant effects of fringing and loss of general definition. The quality of the projected image leaves little to be desired, which is somewhat remarkable when the size of the original image is recalled.

The colour range of Cinecolor is the maximum possible with two primaries, the colour having the indefinable delicacy and charm of additive mixture. The only criticism which can be made is that from a commercial standpoint this process must face certain disadvantages inherent in any additive projection process—namely, the necessity of equipping theatres with a special projection device which must be universally adopted in order to make the world-wide exhibition of a

¹ This process should not be confused with the American subtractive Cinecolor process.

COLOUR CINEMATOGRAPHY

picture practicable—and that it is doubtful whether the resolving power can compare with that obtainable in any process having normal picture size. Recent improvements in the resolving power of positive film, however, would greatly improve the quality of the picture.

CINECOLOR PATENTS

E.P. 346,406, 1930

E.P. 346,454, 1930

E.P. 349,107, 1930

E.P. 388,754, 1931

E.P. 394,385, 1931

Reference

Brit. Journ. Phot., **28**, Colour Supp. (Dec. 1934), p. 48.

Rouxcolor

(16 Av. Victor-Hugo, Vanves (Seine).)

A French additive process. (Two, or three-colour.)

Camera.—The optical arrangement is based upon a patent of L. H. Roux (B.P. 385,141, 1932). In the specification the inventor begins by pointing out that previous optical systems having several objectives behind a single primary object lens had certain defects. One system of this type was composed of a single primary object lens which gave a real image of the object, in the plane of which image was placed a converging lens which directed the rays coming from the primary object lens on to a second optical system formed of a group of identical secondary objective lenses all situated in one plane and whose number equalled that of the number of monochromatic records it was desired to obtain; thus the secondary images are all formed in one plane in which is placed a sensitized surface. Now in such a system the plane of the emulsion of the film is conjugate with a certain plane in the object field of the secondary objectives. The result is that sufficient sharpness will be given only by images from a volume or zone of the object field which is contained between two planes which are very close together, whose distance apart is at the most equal to double the focal length (distance from the focus within which each image of a point object does not exceed a given tolerance) of the secondary objectives (about $\frac{1}{10}$ mm.). For practical purposes this volume would be a plane which itself is conjugate with a certain volume in the object field of the anterior objective, which volume, when focusing to infinity, would lie between infinity and the hyperfocal length. Thus there would be a sharp image only of the space enclosed between the hyperfocal length of the anterior

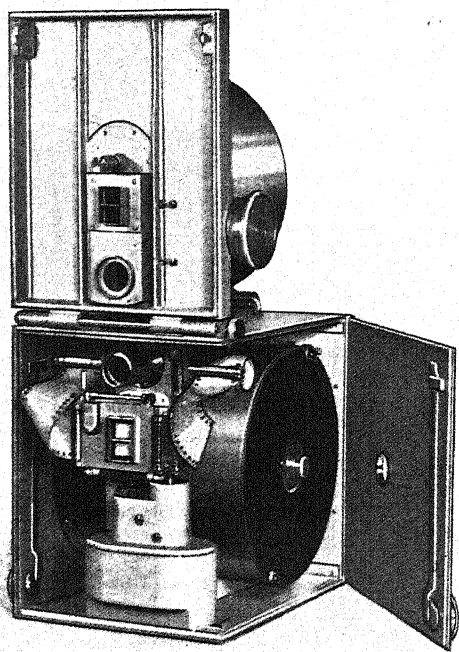
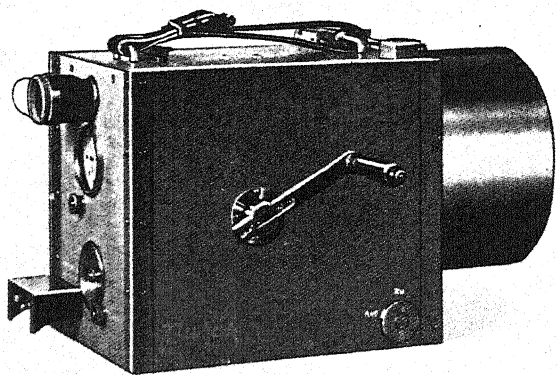


FIG. 142.—The Busch camera.

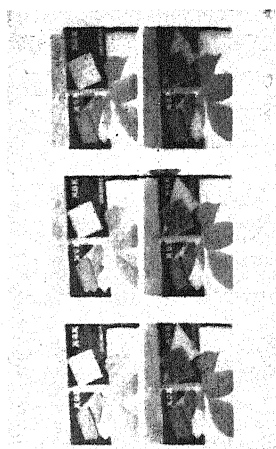


FIG. 143.—Busch negative.



FIG. 148.—Cineoptichrome positive. (See p. 275.)

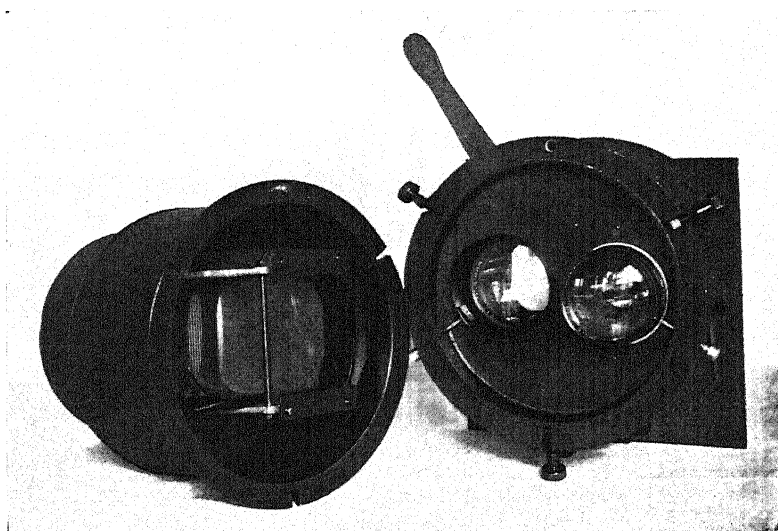


FIG. 144.—Early Cinecolor prism unit for extra width film. Constructed by Adam Hilger Ltd. (Hilger-Workman Patents.)

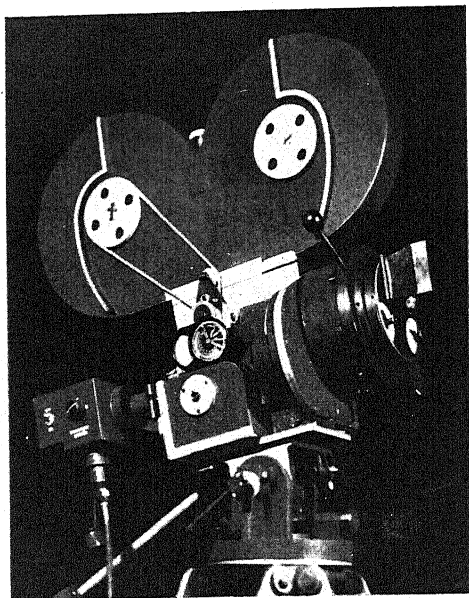


FIG. 145.—Cinecolor camera by Vinten Ltd.
and Adam Hilger Ltd.

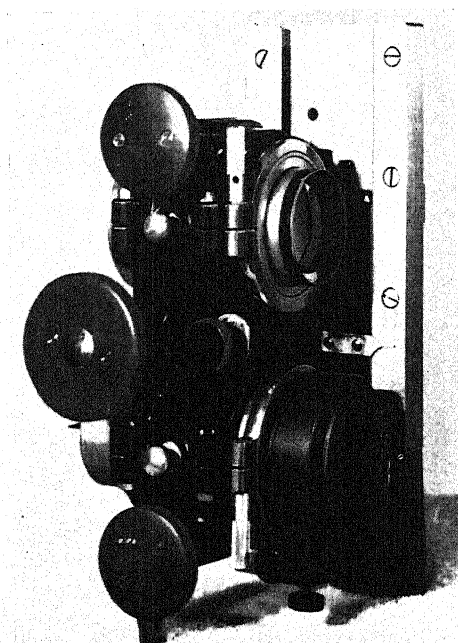


FIG. 146.—Cinecolor projection unit. Note
alternative black-and-white and colour lens.

objective and infinity; all which lies on the near side of this limit would give only a sharp image behind the sensitized surface. There would also be residual parallax due to the fact that the beam which traverses each

Fig. 1

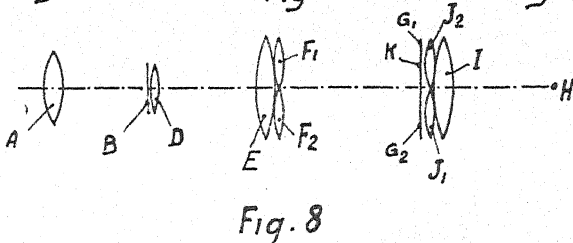
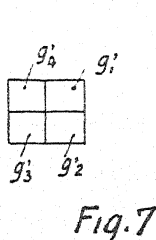
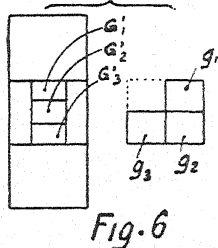
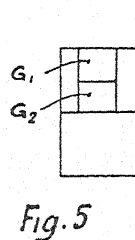
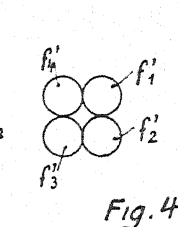
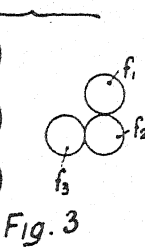
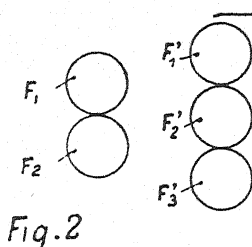
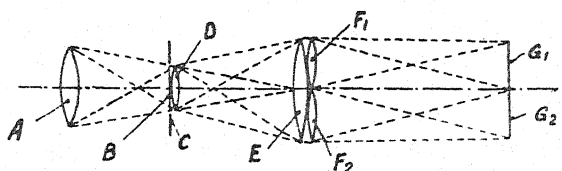


Fig. 8

(Reproduced by permission of the Controller of H.M. Stationery Office.)

FIG. 147.—British Patent 385,141, 1932 (L. H. Roux).

secondary objective has first of all passed through a circular peripheral region in the anterior objective which is the image of this secondary objective given by the interposed optical system, and not through a common region which would be the centre of the anterior objective.

The inventor claims to overcome these defects in the following way. A lens is placed immediately in front of the secondary objective, and this lens projects to infinity the image formed by the primary objective. The focus of this lens is in the plane of the real image formed by the primary object lens. Fig. 1 in the illustration (see Fig. 147) to the specification represents a diagrammatic section of the optical system. Figs. 2, 3, and 4 represent various alternative arrangements of the secondary optical system. Figs. 5, 6, and 7 represent the corresponding arrangements of the images on motion picture film. Fig. 8 is the projection system.

In Fig. 1, A is a suitable objective lens which produces a plane image B. In the plane B is placed a diaphragm so as to limit the field, and a field lens D so as to reduce the divergence of the light beam after formation of the image B; this lens is not absolutely necessary, however. Another lens E, the focus of which is situated in the plane B, is placed immediately in front of a group of secondary objective lenses F'F'' of suitable equal focal lengths. Each of these secondary lenses produces from B a new image G₁ or G₂ in the single plane of their foci, the said images being identical with B and with each other as a result of the focal lengths of lenses F' and F'' being equal.

The introduction of the lens E in front of the secondary objectives F ensures a double advantage according to the inventor. While in the older arrangements the secondary objectives F give multiple secondary images of the single image formed by the primary lens A serving as object for these objectives F, in the arrangement which is the subject of the invention the image formed by A is reprojected to infinity by lens E, and it is the image given by this lens E which acts as object for the secondary objectives F. Whereas in the older systems the sharpness is determined by the focal depths of the secondary objectives, here it is determined by the focal depth of the lens E. The focal depth, for a given aperture, can be shown to be proportional to the focal length, so that the focal depth which is effective in determining the sharpness of focusing is increased in the ratio

$$\frac{\text{focal length of E}}{\text{focal length of F'}}$$

a ratio which in practice is between 2 and 2.5, resulting in a considerable improvement in the focusing.

Further, the lens E practically eliminates parallax. Since the image from the objective A reprojected to infinity by said lens E has (the reprojected rays being parallel) the same aspect in relation to each of the secondary objectives, the latter give images without parallax defects.

It is claimed that the presence of the lens E in the projection system permits of working with the same spacing of the centres of the secondary objectives F as was employed in the camera lens and therefore obviates

any necessity for adjusting said objectives. If the lens E were not provided, it would be necessary to make these objectives adjustable to enable the exact superposition of the images on the screen.

The claims are:

1. Apparatus for cinematograph or other colour photography of the kind in which a first objective gives a real image of which several secondary objectives then give their several images, which may be superimposed and are all situated in one plane, characterized by the fact that a lens, reprojecting to infinity the image formed by the principal objective, is placed in front of the secondary objectives and in close proximity to these objectives, the focus of this lens being in the plane of the real image given by the principal objective.

2. Apparatus for cinematograph or other colour projection, comprising the elements of an optical system arranged as claimed in Claim 1, the direction of projection being the reverse of that defined in said claim for the purpose of photography.¹

Projector.—Lens as described above for the camera. See Fig. 147 (Fig. 8 in specification).

This process was demonstrated at the Institut d'Optique, Paris, March 22, 1934, and again in Paris in 1948.

Remarks.—The writer has not had an opportunity of seeing any pictures projected nor of ascertaining to what extent the claims of the patent are actually met in practice. Apparently four pictures were originally taken within the space of one frame (Fig. 148).

Monsieur J. Vivié of Paris has reported to the writer that the brothers Roux have continued their researches in spite of the war, having further perfected the optical system of the camera, and claim to have eliminated fringing. Four separations are now being taken on each normal frame. As for projection, they had concentrated on the problem of luminous efficiency. It had been found that in order to equal normal screen average luminance (ten foot-lamberts) they were proposing to use a source of light at least six to eight times the normal intensity. It would seem that no such increase is in the least possible, unless it is proposed to reduce correspondingly the screen magnification.

Hillman Camera

(Colourgravure Ltd. and Gerrard Industries Ltd.)

The patents of A. G. Hillman are described in Chapter V. It seems that Mr. Hillman was at one time engaged upon the mechanical work of the Cinecolor process for S. J. Cox and D. Daponte. He left Cinecolor and interested Mr. Kay Harrison of Gerrard Industries Ltd. A company was formed later, known as Colourgravure Ltd., in which com-

¹ Quotations from British Patent Specification by permission of the Controller of H.M. Stationery Office.

pany Mr. Alexander Korda became interested, London Film Productions taking a share interest. Owing to the association of London Film Productions with the Hillman process it received considerable publicity in 1933-4. It was announced that pictures would be filmed by Mr. Korda, but no pictures were ever released, and this may have been due to the fact that a camera made according to the Hillman patents would have little chance of avoiding serious defects of time-parallax, and to a less extent of space-parallax. Nor, at the time, was any announcement made as to the proposed method of presenting films taken with the camera. Were they to be projected by some additive device? Or were they to be printed by one or other of the available two-colour processes? But when London Film Productions adopted Technicolor (subscribing some £50,000 to Technicolor Ltd.) it became unlikely that the Hillman camera would ever be used.

In the Hillman camera *two frames* were exposed simultaneously one above the other. In front of the apertures in the gate was an oscillating filter element having three filters—red, green, red. The first two frames were exposed through the green and red filters, say, the film was then moved down *one frame* and the filters moved too, so that at the next exposure the frame, which had already been exposed to green, *received a second exposure through the same filter*, while the next unexposed frame came into position above to receive an exposure to red. The film then moved down another frame and the filter moved up, so that the frame which had just received a red exposure received another exposure through the other red filter, while the following frame was exposed for the first time to green. Thus obviously each frame received two consecutive exposures through its appropriate filter. Time-parallax fringing would thus be inevitable.

The two images were obtained by a pair of lenses in front of which was a mirror system comprising an inclined stainless steel mirror in front of the upper lens with a hole through which rays passed to that lens, the remaining area of the mirror reflecting the beam to the second mirror, which was in front of the lower lens and inclined thereto at an angle of 45°.

Projection.—Described in E.P. 478,501.—Films carrying groups of three colour record images were fed through a projector by single-image shifts at approximately the same speed as the negatives from which they were made, and the images were projected simultaneously in pairs, each first with the preceding image and again with the following image; the negatives from which they were printed had images exposed in a similar manner, or pairs of images simultaneously exposed together twice. The projector had two adjustable objectives, a two-image gate, a single-image intermittent mechanism, and a rotating filter disc comprising groups of filters of which 1 and 4 were blue, 3 and 6 were green, and 5 and 2 were red. See also E.P. 483,817.

ADDITIVE PROCESSES : THREE-COLOUR

The design of a beam-splitting system free from parallax and capable of taking three geometrically identical images is a matter of extreme difficulty. The attempt made by Gaumont¹ in 1912, in which the

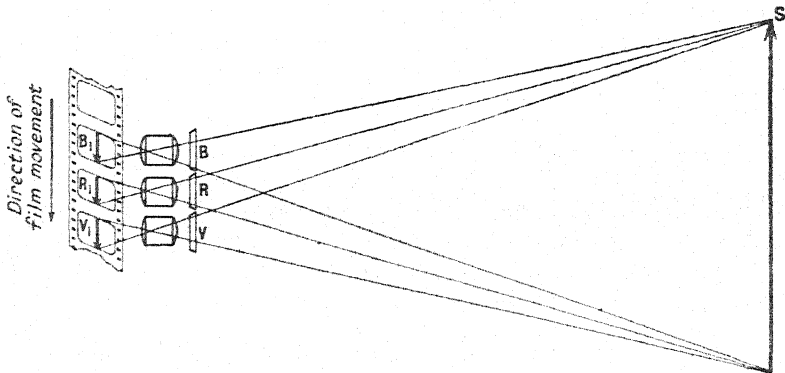


FIG. 149.—Gaumont System. (E.P. 3,220, 1912.) "Sawn-off" lenses were used.

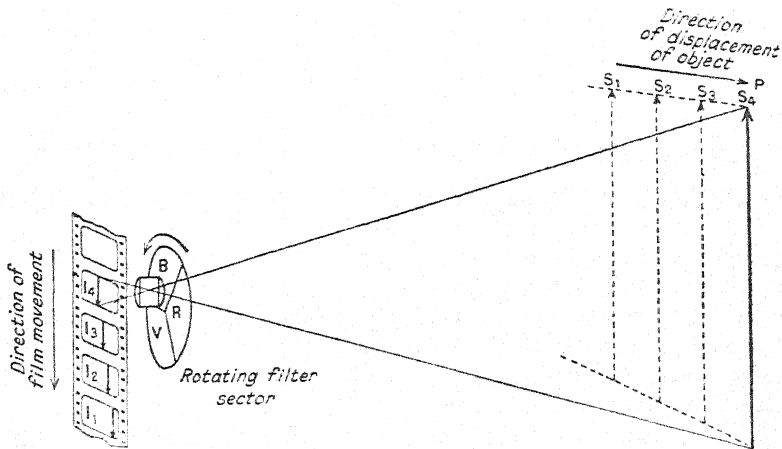


FIG. 150.—Gaumont Successive Exposure.

pictures were taken by three sawn-off lenses disposed vertically one beneath the other, failed owing to the presence of serious parallax. The pictures in this camera occupied 2.25 times the length of a normal frame instead of three times the length (Fig. 149). Gaumont also tried successive exposures using a rotating colour filter disc in front of the objective. Fringing from time parallax was obviously excessive (Fig. 150).

¹ Société Établissements Gaumont.

The process of J. Szczepanik in 1925 was impracticable. He used a non-intermittent camera having a chain of eighteen lenses moving together with the film behind a collimating lens, three pictures being simultaneously exposed¹ (E.P. 238,973) (Fig. 151). The writer came across this queer camera a short time ago and took the opportunity of recording the grave of one more inventor's bright hopes (see Fig. 152). The camera has since been destroyed.

A number of attempts are of French origin. M. Audibert patented an optical system (E.P. 355,835, 1930) in which three objectives were used behind a large divergent lens. Such an arrangement considerably

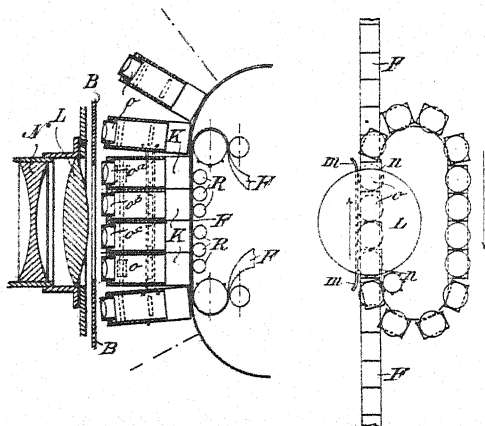


FIG. 151.

reduces parallax. A camera was made which took four full-sized frames on 65-mm. film (Fig. 153). By means of a special optical printer these negatives were printed with the aid of analysis filters on Lumière mosaic film. This type of film had an irregular starch grain screen similar to the Lumière screen plate, but it was very opaque and the results were not very satisfactory.

P. E. Bonneau proposed to take (E.P. 408,499, 1923) three full normal-sized negatives on extra-width film, and to reduce them to miniature positives by optical printing so that they occupied the space of a normal frame. V. Hudeley would take three small pictures within the space of a single frame, afterwards enlarging them and printing through colour screens upon lenticular film (E.P. 408,764, 1933).

¹ A three-colour continuous motion camera was worked out by W. E. Johns (E.P. 16,200, 1916). Fifteen lenses; horizontal movement. Time-parallax is present.

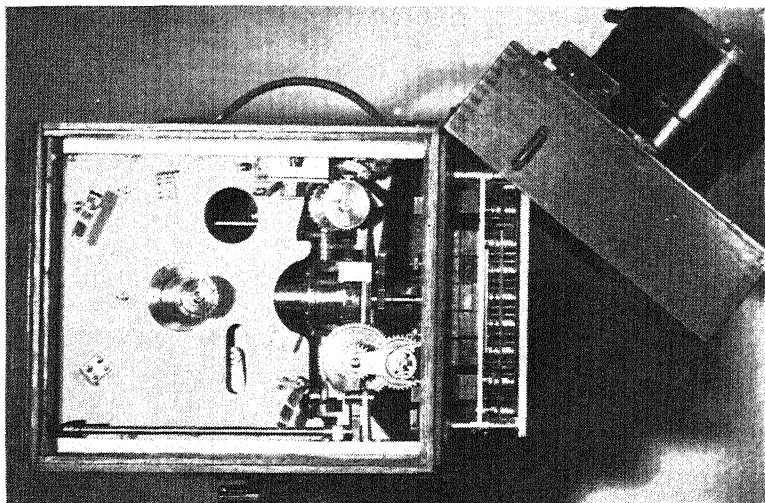


FIG. 152.—Szczepanik multiple lens continuous motion colour camera.

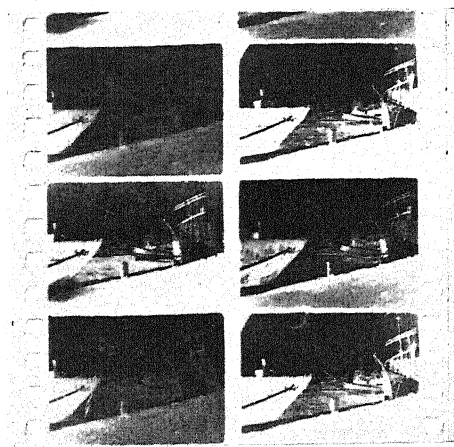


FIG. 153.—Negative exposed by Audibert optical system. 65-mm. film.

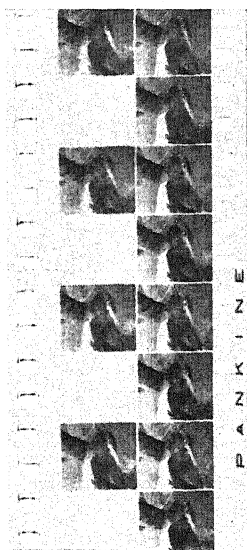


FIG. 154.—Bassani negative.

EXAMPLES

Bassani Process. (Probably Obsolete.)

(Société Chromofilm, Paris.)

Camera.—An interesting camera was made by the Société Chromofilm, Paris. An astonishing mechanism moved the *entire gate*, and film within it, at each exposure, with reference to the normal fixed objective. Three miniature negatives were exposed, by the successive movements of the gate, within the space of a normal frame. Actually there were 96 movements of the gate per second, but the pictures were exposed at the rate of 72 per second (Fig. 154).

Projection.—The positive was projected with a triple-divided sawn-off lens with suitable registering adjustment. Save for slight time-parallax fringes (especially in close-ups), owing to the non-simultaneity of the negative records, the results were admirable, apart from the question of practicability of additive processes of projection (E.P. 447,225).

Francita Process.¹

(Operated in Great Britain prior to 1939 by British Realita Syndicate Ltd. See also Société de Films en Couleurs Naturelles Francita.)

Camera.—Two substandard pictures, each approximately 8×12 mm., were taken on two diagonally arranged parts of a normal image area. These were the red and green filter negatives. The film was then moved by *half* the height of one frame and a third picture exposed in the then remaining space under the upper of the two pictures already exposed at the diagonals of the frame. Thus only two lenses were required. The beam-dividing system consisted of a pair of polished metal mirrors placed in front of the two objectives, one of the mirrors having an aperture. This type of beam-splitter exhibited a certain amount of parallax, since one objective was nearer the object photographed than the other by a distance equal to the separation of the two mirrors. The pictures were taken at the rate of 48 per second. Thus a red and a green record were always exposed together, followed by a blue record. The time-parallax fringe was undesirable (Figs. 155 and 156).²

Projection.—A normal contact black-and-white print was made from the negative and projected, as usual with processes of this type, by means of a split triple objective embodying the additive primary colour filters. Means were provided for independent registration of each image upon the screen.

¹ Known also as Francita-Realita. In England called Opticolor. Process developed by Maurice Velle.

² Francita later gave up this type of beam-splitter. Use was later made of the patents of J. M. Gutmann and P. Angenieux. The three separations are made simultaneously and parallax was claimed to have been eliminated.

Remarks.—A feature film was made in France by the Francita process, and it was exhibited in July 1935 at a Parisian cinema. The colour was very fine indeed in parts of the film, and any defects were due to poor lighting rather than to the process. This film proved that were it not for the serious commercial problem of a special projection apparatus, with the likelihood of its getting out of adjustment, the subtractive processes would have a serious competitor in additive systems of this type. Considering that the positive part images were of substandard dimensions, it is remarkable how good the definition was. A limited amount of fringing was perceptible in close-ups.

Films of the Coronation of H.M. George VI and "Trooping the Colour" were exhibited in London at the Cameo Theatre and elsewhere in 1937 with considerable success. Slight fringing was occasionally

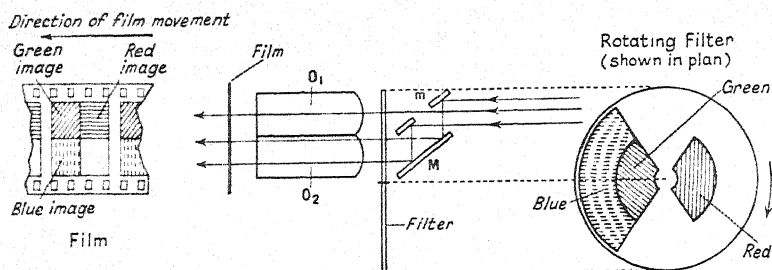


FIG. 157.—The Francita Process. Schematic Diagram. The arrangement of mirrors m and M at 45° to the axis of the objective O_1 enables coincidence to be made between this axis and the axis of the Objective O_2 . During the still period of the film a filter disc is turned in front of the lenses. For a certain position of filter and film both blue and green images are simultaneously exposed, no space parallax being involved. After moving the film forward half-a-frame and the filter a half-rotation, the red image is recorded, which involves time parallax in relation to the former two negatives. The projection system is identical.

apparent. The brightness of the projected picture was rather poor, as must inevitably be the case with additive processes. These films were also shown in France, Belgium, and Holland.

Apparently work on this system had not been abandoned in 1945. Keeping the camera optical system unchanged, it is now proposed to make prints from the substandard negatives so obtained by some unspecified subtractive process using optical enlargement. Ansco Color or Agfacolor might be used, or an additive process such as Dufaycolor could be used if the printing were done by three successive stages employing tricolour filters (Fig. 159).

Pinchart Process. (1948)

French additive three-colour process.

Camera.—The quadruple objective "A" records four images on the film. In front of this bundle of lenses is a sectional filter divided into

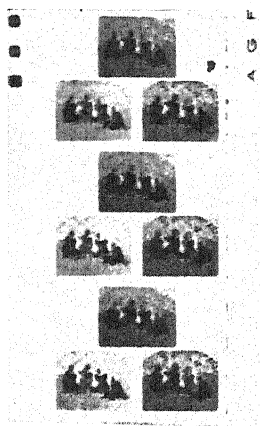


FIG. 155.—Francita negative.
(Earlier arrangement.)



FIG. 156.—Francita positive.

blue, green, red, and a neutral grey which is supposed to improve modelling. In optical systems incorporating sawn-off objectives the images of a print are not circular and are in fact asymmetrical. Consequently the four point images corresponding to any real points are not identical (B), but leave all around the square middle part, areas lacking complete synthesis, which, if nothing was done to compensate for this

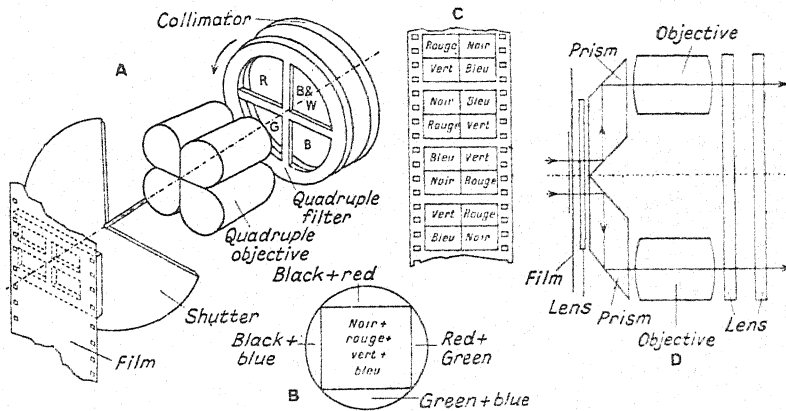


FIG. 158.—Pinchart Process.

error, would lead to lack of colour balance. To eliminate this defect the filter unit is rotated one quarter of a turn for each exposure, which results in a cycle of colour records differing from one four-part frame to the next. This would require a rotating filter for projection (D shows the system in side elevation), but this is ingeniously dispensed with by dyeing each part frame uniformly with the correct colours (Fig. 158).

Projection.—No description available.

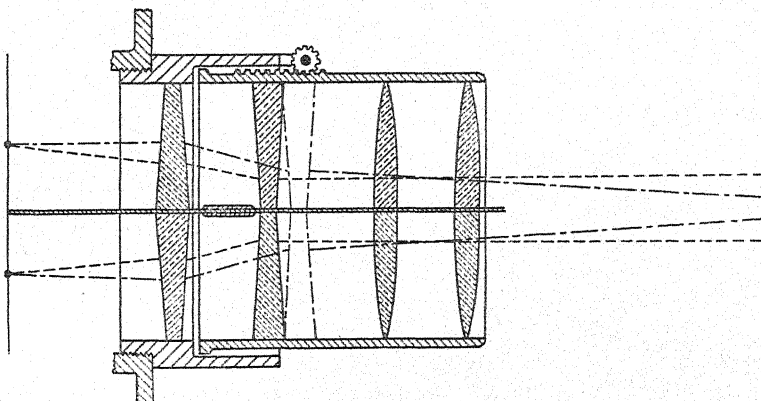


FIG. 159A.—Thomascolor Projection Lens. (E.P. 453,221.)

Herault Trichrome Process. (Probably Obsolete.)

Additive three-colour process.

Projection.—The black-and-white positive made by contact from the original negative was tinted in red, green, and blue dyes on the appro-

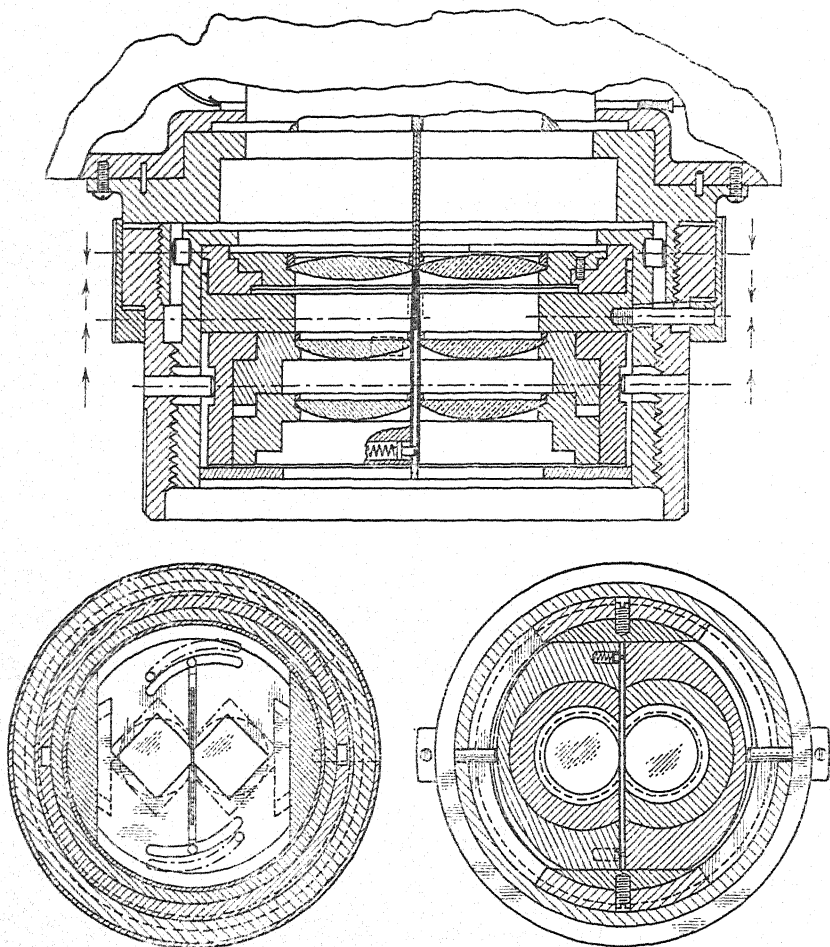


FIG. 159B.—Thomascolor Camera Lens. (E.P. 453,221.)

prate frames. It was then additively projected at 24 frames per second by a non-intermittent projector (F.P. 665,807).

Thomascolor. (Richard Thomas Enterprises.)

Classification.—American additive process. Quadruple objective camera lens unit (Figs. 159A and B). Anti-parallax optical system

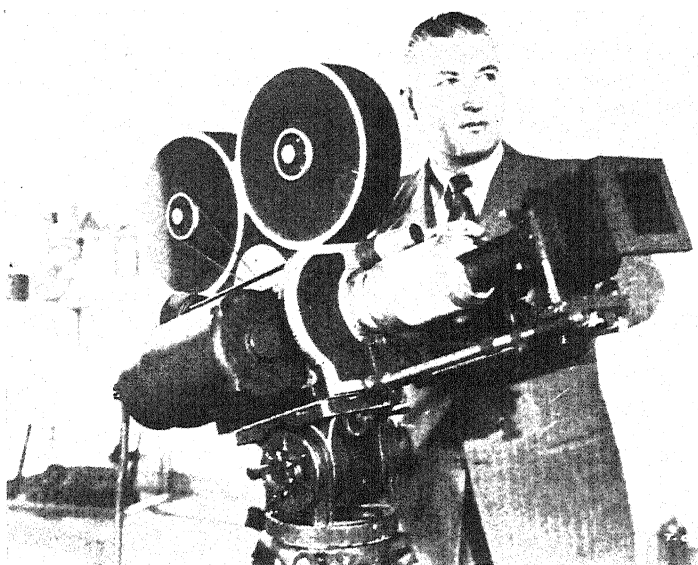
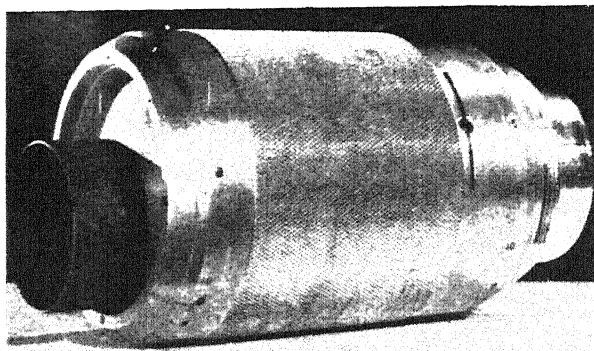
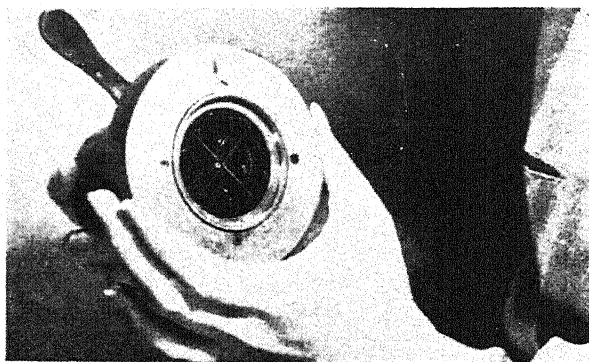


FIG. 160.—Thomascolor camera.



Thomascolor camera lens.



Projection lens.

FIG. 160A.

unknown. Four images occupy the area of a normal standard frame (E.P. 453,221). Type 3D beam-splitter (see Chapter V).

Camera.—Normal, equipped with the Thomascolor quadruple objective. A number of foci are available (Fig. 160).

Negative.—Normal.

Positive.—Normal.

Projection.—Special quadruple objective with single control of registration of the four images on the screen. A locking device is claimed to prevent subsequent shifting.

Comments.—Thomascolor is the only additive process at present being commercially exploited in U.S.A. Mr. Richard Thomas has spent fifteen years in developing the optics of this system, but so far there exists no reliable information as to the detailed design of the camera objectives nor of the projection unit. An extremely uninformative and very verbose description appeared in *American Cinematographer* (May, 1944), p. 154, but from this article nothing whatever is to be extracted of the slightest value. It would not seem that Thomas has improved in any vital respect on very similar optical systems already made familiar by French processes such as Francita and that of Roux. It is stated in the description referred to above that Air Chief Arnold was much impressed. And the following absurd claim appears: "Since four color separation images take the place of a single 35 mm. black-and-white frame, the same area of light is actually transmitted to the screen as when black-and-white pictures are shown." This is supposed to imply that the screen luminance will be equal! We need not make any further comment. Another marvellous statement is "Superimposition of one colour upon another eliminates any disposition to graininess and intensifies the brightness range of the colors." (See Kistler, L. R., *Intern. Projectionist*, 20 (July 1945), pp. 12-14.) We may take the liberty of suggesting to Mr. Thomas that he would gain the respect of technicians more surely by presenting his process to the world in language comprehensible to men of science even if he has to risk unpopularity with newspaper reporters.

MOSAIC PROCESSES

Involving no Optical Change from Normal Procedure

Again we must give that genius Louis Ducos du Hauron the credit of being the first to conceive the idea of dividing the photographic record into a large number of semi-microscopic primary elements, each one a minute colour filter, instead of making three separate "continuous records" [1].

E. J. Wall suggests that du Hauron thought of applying the principle of technique of the school of French painters known as the "Poin-tillistes," and this was the laying-down of juxtaposed minute dots of

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colour instead of superposing three films.¹ Wall notes that: "It is obvious that this is essentially an additive process, and not subtractive, as to make violet, minute dots of red and blue are placed side by side, and to make yellow, minute dots of red and green."

Ducos du Hauron, in his French patent, said:

Enfin, il existe une dernière méthode par laquelle la triple opération se fait sur une seule surface. La tamisage des trois couleurs simples s'accomplit non plus moyens de verres colorés mais au moyen d'une feuille translucide recouverte mécaniquement d'un grain de trois couleurs.

Which may be translated:

Finally, there is another method by means of which the triple operation may be effected on one surface. The separation of three elementary colours need be effected no longer by three coloured glasses, but by means of one transparent sheet covered mechanically with a grain of the three colours.

The following classification of mosaic processes was suggested in a paper on the subject by C. E. K. Mees and J. H. Pledge [2]:

1. Ruled lines.
2. Dusting-on methods.
3. Section cutting.
4. Mechanical printing, or combination of mechanical methods and dyeing.

The first line screen was probably made by Professor J. Joly [3]. He was followed by J. W. McDonough and others. McDonough was apparently the first to patent the dusting-on method [4]. This method was eventually commercialized in the Autochrome and Agfa plates and films. The former was based upon the patents of Société Anonyme des Plaques et Papiers, A. Lumière et ses Fils [5]. The Agfa plate was based upon J. H. Christensen's patent [6].

Proposals for the application of the mosaic principle to motion picture film date back in any case to L. Vidal, who suggested the use of the Joly screen [7].

It has been shown that the resolving power of the eye is of such an order that it will see coloured lines as separate if their "period" (twice their separating distance for lines of equal width to the spaces) is about $\frac{1}{800}$ of their distance from the eye. W. Scheffer² had shown that horizontal black lines were visible if their period was $\frac{1}{1000}$ of their distance from the eye. E. J. Wall noted that blue and green tend to blend before red.

Dufaycolor 35-mm. film has 20 lines to the millimetre. From Wall's statement it should follow that the screen (*réseau*) would still be visible

¹ The Pointillistes, and also the whole school of painters grouped as the Impressionists, never properly grasped the nature of the additive primaries, since they invariably referred to these as red, yellow, and blue, juxtaposing yellow and blue with the intention of rendering green.

² *Phot. Rund.*, 1919; *Brit. J. Phot.*, 1909, 56, *Col. Phot. Supp.*, 3, 62, 70; *Phot. Kor.*, 1910, 47, 588.

at some 60 ft. in a theatre having a 25-ft. screen, since the lines would be about 8.5 mm. wide on the screen. As a matter of fact the screen is invisible at 60 ft., and also at 30 ft. The magnification being 340 times linear, and each line being 0.025 mm. in width, the size on the screen would be 8.5 mm., which would subtend an angle of 1' 35" at 60 ft. (1' 30" is the limit of resolving power for the eye). However, the visibility of the screen image seems to be much reduced at smaller distances by the additive effects due to movements of the position of screen elements during the projection of 24 successive pictures per second.

Dufaycolor is the only mosaic film which has so far been used with any success for cinematographic work.¹ The process had its origin in the screen plate of Louis Dufay, which was sold from 1910 to 1917 as the Dufay "Diophtochrome" plate. E.P. 11,698, of 1908, describes the method of manufacture. A master ruled screen consisting of parallel ruled lines is used to print upon a bichromated gelatine surface coated upon glass or film. This is developed and dyed in one of the three primaries. It is then inked up like a collotype plate. The ink takes on the hardened parts of the plate and not on the coloured lines. An impression is taken upon a plain gelatine-coated plate. The latter is then varnished. The varnish adheres to the parallel lines between the impression of the greasy lines. Upon dissolving the greasy lines² [8] with benzine, clear spaces are alternately left between parallel coloured lines. The second printing is done at right angles to the first. Lastly, the third colour is applied all over the plate on a surface of saturated gelatine. Thus a screen was made by a series of imbibitions.

E.P. 20,111, of 1908, of Société Anonyme des Plaques et Papiers, A. Lumière et ses Fils, largely covers the same ground. It is proposed to apply parallel lines of some resist, such as a greasy ink, to gelatine dyed with one of the colours, and to destroy the colour in the intervening space. A second series of lines was printed at right angles to the former and the same operation repeated. At this angle a moiré pattern would have been produced, however. In E.P. 322,433 is described the angles used in the Dufay screen to avoid moiré.

E.P. 217,557, of 1923, describes a manufacturing technique which when fully developed led to the present Dufaycolor process.

DUFAYCOLOR

(Manufactured by Dufay-Chromex Ltd., London, England)

Classification.—Three-colour additive screen (mosaic or *réseau*) process. 35-mm. negative-positive professional motion picture film.

Camera.—Normal.

Projection.—Normal.

¹ Mondiacolor, a French four-colour mosaic film, has recently been described; it is said to have 1,800 elements per square millimetre (1948).

² First suggested by Bercegol.

THE MANUFACTURE OF RÉSEAU

The film base hitherto used for the manufacture of Dufaycolor film has been cellulose acetate, or butyrate (safety film). Methods have been worked out for its manufacture in the future, if need be, on cellulose

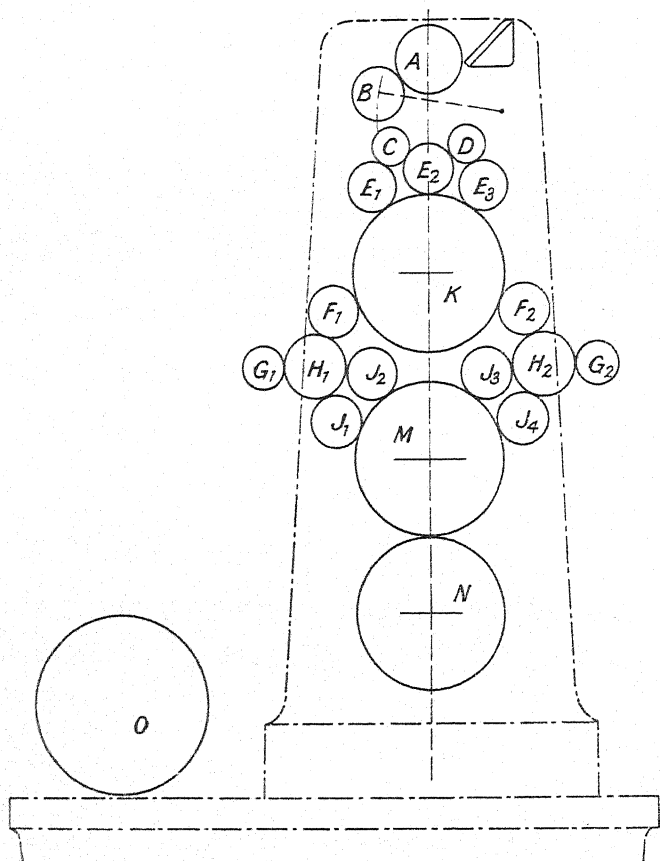
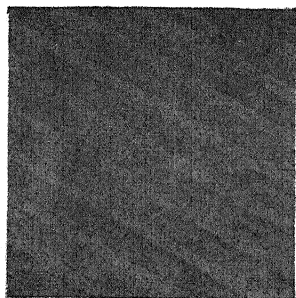


FIG. 162A.—Arrangement of rollers on the Dufaycolor Réseau printing machine.

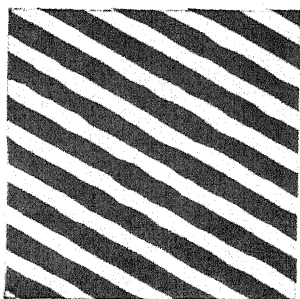
nitrate base identical to that hitherto used for standard black-and-white motion picture film.

The process of making the exceedingly fine pattern of red, green, and blue, constituting the *réseau* (French: *réseau*—a network) of Dufaycolor film, involves a number of stages all of which require rigorous control (Fig. 161).

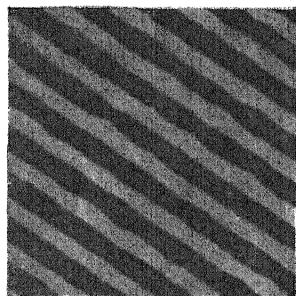
The preparation of film base for the first main operation of coating with blue-dyed collodion is divided into two stages:



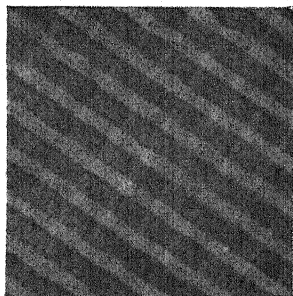
(1) Base dyed blue, then over-printed with greasy resist in lines.



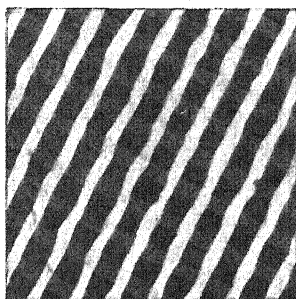
(2) Blue bleached out.



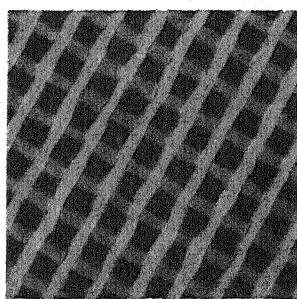
(3) Dyed green.



(4) First resist washed off and reprinted in lines at right angles to the first set.



(5) Bleached again.

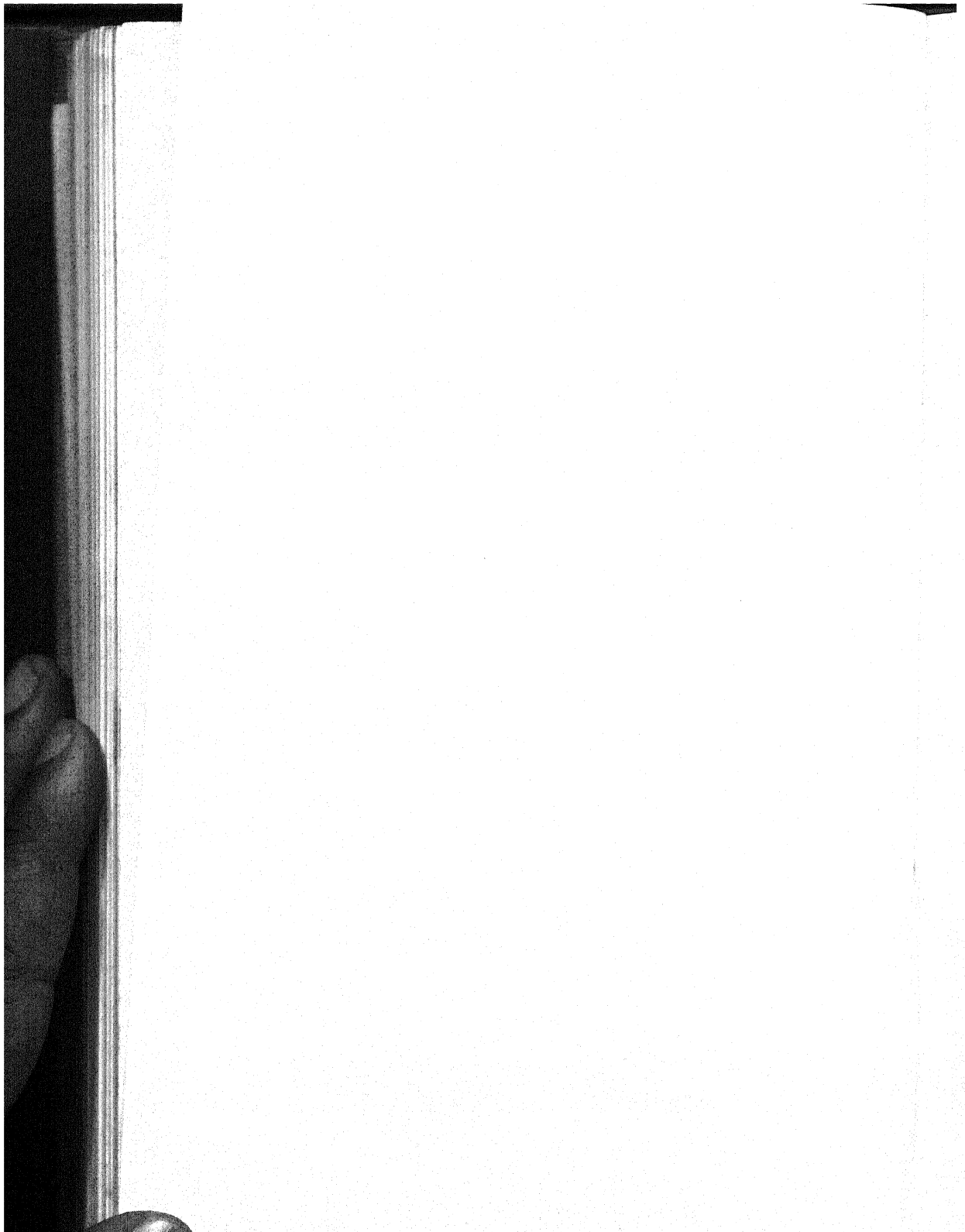


(6) Dyed red and resist removed to give final réseau.

(Courtesy of Messrs. Dufay-Chromex, Ltd.)

FIG. 161.—Photomicrographs of Dufaycolor Réseau.
Magnification $\times 100$ Linear.

These photomicrographs were taken on Dufaycolor Film, the reproductions being made from the transparencies.



- (1) Examination of base for defects. All defects are charted, such as casting-skin drying marks.
- (2) Wiping to remove dust.

Coating of Blue-Dyed Collodion

The coating machine consists of an unwind assembly, a backing device, a coating device, a means for imparting motion to the film without making any contact with the coated face, a drying track, and a rewinding apparatus. Motion is imparted to the film by suction on the back of the film exerted through a travelling endless blanket. An assembly of rollers enables an anti-curl backing to be applied to the film prior to the application of the blue collodion layer. The blue collodion is coated from a trough of special design by pick-up method, the depth of coating being controlled by the viscosity of the solution. Variation of speed will also affect the thickness of the coating. The blue coating is dried at not less than 95° F. and takes about four hours.

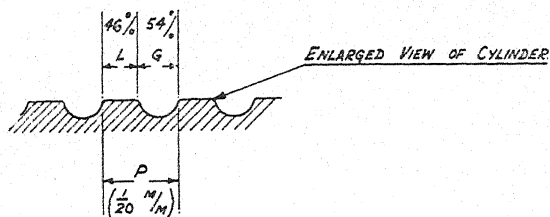


FIG. 164.

Printing First Set

The film is wiped and examined and is then ready for the printing of the "first set," namely the first set of resist lines between which the blue-dyed collodion will be subsequently bleached and re-dyed green. Figs. 162A and 162B show the general arrangement of the Dufaycolor printing machine.

The printing is accomplished by means of an engraved roller or printing cylinder (Fig. 163) upon which is engraved a helical groove of twenty lines per millimetre at an angle of 23° to the edge of the cylinder. Fig. 164 indicates the dimensions of the engraving. The printing ink is finely milled in a special medium and coloured pale blue for recognition purposes. The utmost care is taken to eliminate dust at this stage and photoelectric and micrometric controls track each stage. Fig. 165 shows the roller engraving in section.

At the end of each roll a portion of the film is left unprinted. Part of this unprinted film is coated with a layer of bitumen so that the original blue collodion coating is unaffected by the subsequent bleaching and

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drying, providing a large area of green for spectrophotometric check and record.

Bleaching and Dyeing Operation

The film, now bearing printed lines in greasy ink, is drawn over a suction table, through a hot box, and coated on the back with bitumen,

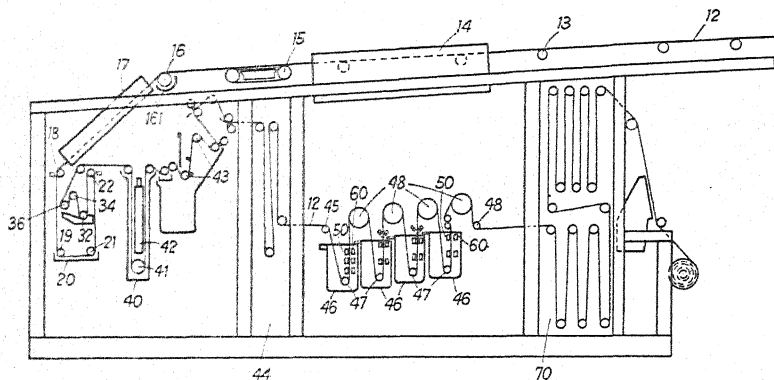


FIG. 166A.—Flow of film through Dufaycolor Dyeing Machine.

The film (12), having the side with the resist lines uppermost, is carried over a number of rollers (13) through a hot box (14). To keep the film taut throughout the machine a suction table (15) is used, after which the film is fed over a driven backing roller (16) which deposits a protective layer on the underside of the film. This layer is dried by passing the film through a second hot box (17).

The film is now in such a state that it can be bleached, dyed, and cleaned without attack or injury to the side not being treated.

It is then bleached on the resist line side by being run over a roller (18) through a first curtain of bleach, afterwards passing through a bath of bleach (20) and finally over roller (22) through a second bleach curtain.

After bleaching, the film is run under roller (32) through a stop bath which arrests the action of the bleach. The film is then immersed in a dye tank (40), in the centre of which is a water leaf (42) which controls temperature of dye. A thermostat bulb in the dye regulates the temperature of the water feed to the leaf. On leaving the dye tank the film passes through another stop bath before having the excess dye removed.

This is done by means of water sprays applied at points round rollers (43) over which the film passes. Any spots of water which adhere to the film are then removed by high pressure air blowers, after which the film passes through a drying chamber (44).

The film has now not only the required dyed lines on it, but still retains the resist lines and the protective layer. The removal of the resist lines and the protective layer is done by passing the film through a suitable solvent which is contained in a series of tanks (46), which are so arranged that new solvent fed into the last tank cascades from it through intermediate ones into the first tank, the overflow from which is carried away from the machine. Suspended in each tank are the necessary rollers (47) for carrying the film, and there are also sets of wipers (50 and 60), which assist in the removal of the resist lines and the protective layer.

The film now passes through a drying chamber (70) before being re-wound ready for the next operation. A viewing box is situated between the chamber and the re-wind in order that visual appreciation can be made of the results of the dyeing operation.

dried, and then carried through a first and second bleach weir. Now it enters the dye tank, to be dyed green, from which it passes to a spirit-water wash, thence through a spray water wash, through blowers for removal of excess water, over a roller running in distilled water and into a drying chamber. Next it passes through four ink solvent tanks with wipers to assist removal of the ink traces, after which the film enters a final drying chamber, and from thence it is re-wound (Fig. 166).

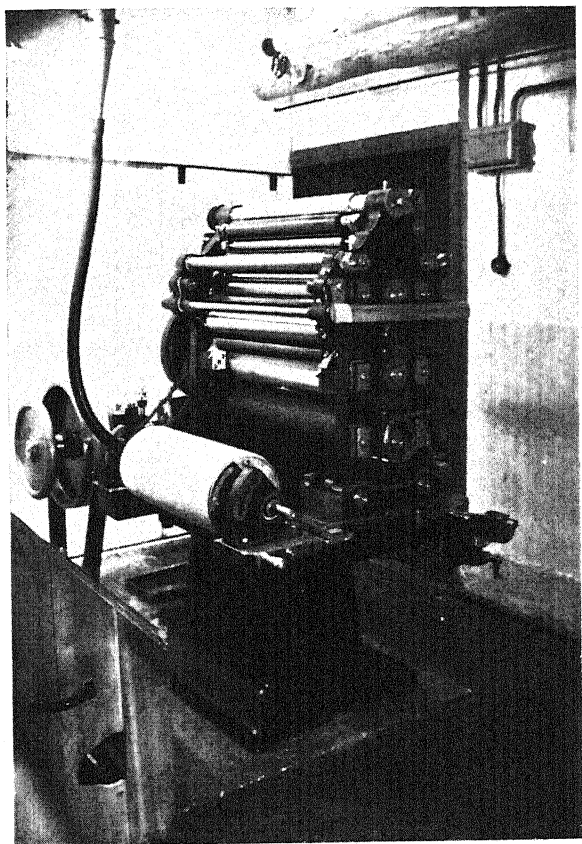


FIG. 162B.—Dufaycolor *réseau* printing machine.

This machine prints in a greasy ink 20 parallel rulings to the millimetre at an angle of 23° to the edge of the film. The transparent non-flam. base has previously been uniformly coated with the blue primary colour—the superfine Dufaycolor greasy ink being employed as a “resist.”

Subsequently the space between these lines is bleached and dyed with the green primary colour, and the “resist” dissolved; thus leaving two parallel coloured lines each $\frac{1}{10}$ mm. ($\frac{1}{1000}$ inch) in width.

The operation is again repeated with the red primary colour at an angle of 67° to the edge of the film.

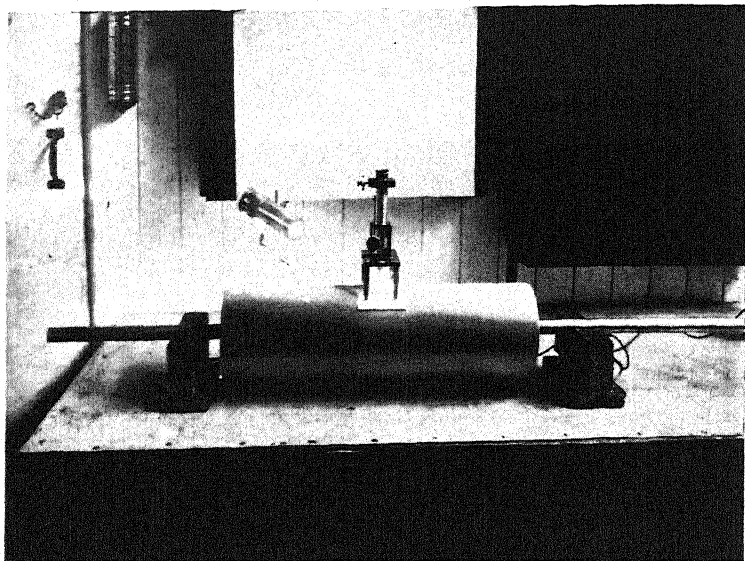


FIG. 163.—Dufaycolor *réseau* engraved roller set up for examination. This is engraved with 20 parallel rulings to the millimetre. The rulings are engraved at an angle of 23° to the edge of the roller.

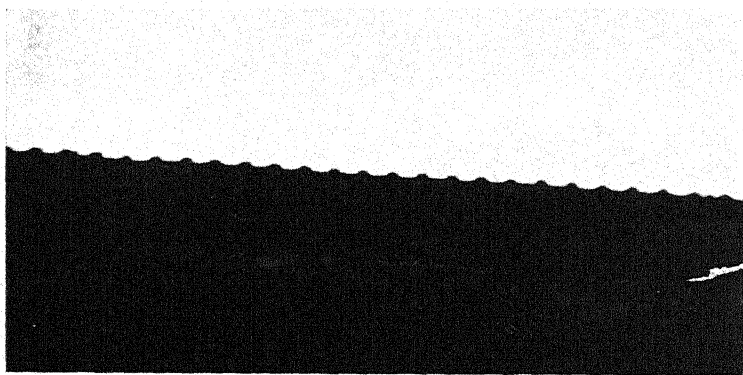


FIG. 165.—Photomicrograph of section of Dufaycolor printing cylinder.

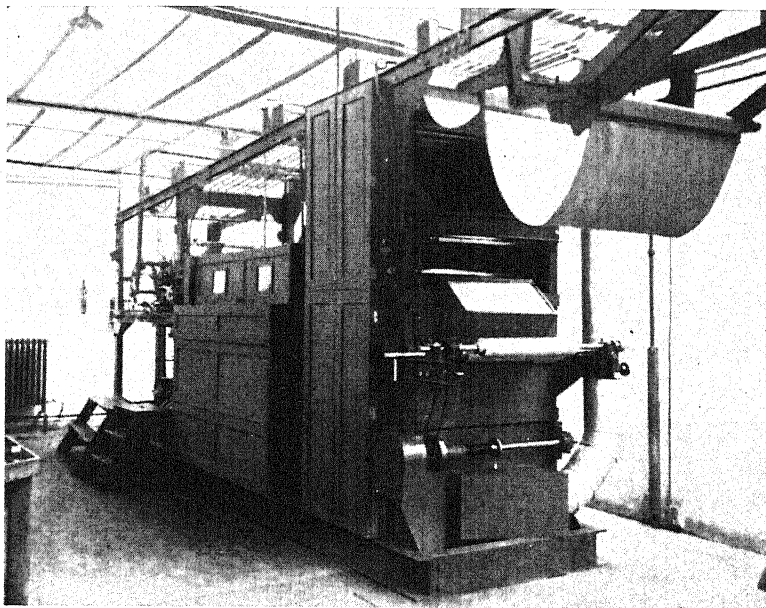


FIG. 166.—Dufaycolor *réseau* dyeing and bleaching unit.

The inspection end of the machine is nearest the camera. The finished *réseau* at any stage passes across the viewing light and is inspected here.

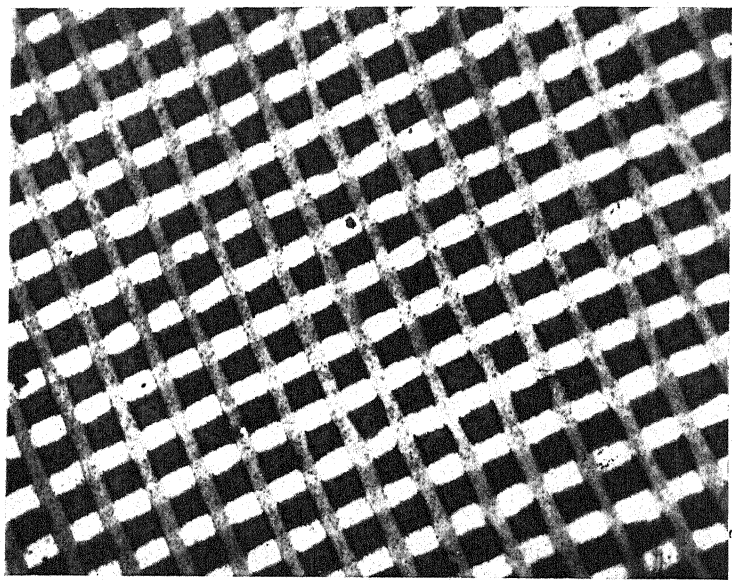


FIG. 167.—Photomicrograph of Dufaycolor *réseau*. Magnification $\times 100$ linear. The darkest squares are blue, the lightest green, and the continuous lines are red. There are nearly one million of these elements in one standard ciné 35-mm. frame (0.631 in. \times 0.868 in.).

Inspection of First Set

When the first set has been completed the whole roll is examined. The roll is unwound in front of a view-box illuminated with tungsten light corrected to Illuminant B (C.I.E.). A visual match is made continuously along and across the roll with a card bearing standard pieces (graded) of first-set *réseaux*. A copy of the recorded data is passed on to the production department for their use prior to the second set being printed. The view-box is fitted with a microscope permitting inspection of any point on the film. Routine examination consists of:

- (1) Description of the line (straightness, evenness of edge, number of breaks, etc.) under both high and low power objectives.
- (2) An estimate of the amount of penetration of the inked line.
- (3) An examination of a sample of any spots, noting whether they are normal or abnormal.

Printing Second Set

The *réseau* is prepared for printing, bleaching, and dyeing second set in a precisely similar manner to first set. Second-set cylinders are engraved with lines at right angles to those of the first set.

Bleaching and Dyeing Second Set

The only difference to first set is that the dyeing is red.

Examination of Second Set

Colour.—The viewer is fitted with a colorimeter which can be moved horizontally across the width of a roll so that measurements can be made of any desired spot. The area measured is about $1\frac{1}{2}$ in. diameter circle and is matched in terms of additive values of tricolour filters. If the colour is found to be outside a certain tolerance area the film is back-coated with a subtractive filter for modification of its chromaticity. A detailed map is prepared of the colour characteristics throughout each roll.

Varnish Coating and Backing

The final operation prior to emulsion-coating consists in applying a resinous water-impermeable layer to the surface of the *réseau*, the dyes of which would otherwise desensitize the emulsion. Immediately after application of the varnish layer, a solution of gelatine is coated on the tacky varnish and if necessary a corrective dyed gelatine back-coat applied by the same machine at a point immediately following the varnish application. The varnish takes about fourteen hours to dry at a temperature of about 115° F.

Final Inspection

Followed by:

Preparation for Emulsion Coating

The film receives a final wash in a spirit-water mixture to remove any microscopic traces of loose dye. It is then spooled and packed for storage until it is to be coated with emulsion.

Remarks.—Dufaycolor *réseau* is printed with twenty and for certain purposes with twenty-three lines to the millimetre, each line being $\frac{1}{40}$ mm. in width (Fig. 167). Considering the complexity of the manufacturing process, it must certainly be considered the most extraordinary piece of printing ever achieved. The printing is remarkably even and very few irregularities occur. The individual line under the microscope is not absolutely even in width, but this is compensated for by averaging. The printing machine is a superb example of precision engineering, especially when the speed of printing is recalled, namely 10 ft. per minute.

COLORIMETRIC SPECIFICATION OF RÉSEAU ELEMENTS

	x.	y.	Y (%).	Dom. Wave- length ($M\mu$).
Red Element	0.633	0.365	17.7	601.7
Green Element	0.233	0.647	43	549.6
Blue Element	0.14	0.089	3.7	466.0

Negative-Positive Processing

The original Dufaycolor 35-mm. ciné film is developed as a negative, and prints are made by contact on Dufaycolor positive, a practically normal machine being employed, except for modifications in the light-source and light-control.

By means of the "depth developer" of D. A. Spencer (see page 312), development is restricted to the lower level of the emulsion layer in immediate contact with the *réseau*. This eliminates desaturation due to irradiation and *réseau* image-element spread. In the words of the inventor [12]:

Assume that a pure red object has been photographed. In the resulting negative the red elements should be masked by black silver, and the green and blue elements, through which the red light from the subject cannot pass, should be transparent. Owing to the spreading of the silver image, however, these elements are partially masked by developed silver. When now we print from this negative upon similar material, to obtain the final positive, a similar unwanted scattering takes place accompanied by a further degradation of the colours.

It might at first be thought that an increase in exposure during printing would compensate for the reduction in the luminosity of the green and blue elements

which results from the density produced by light scattered from the red recording region. It must be remembered, however, that the spreading of the image is taking place from every element through which light passes and is, therefore, in effect tending to even out the amount of opaque silver produced under each element. Since the rendering of colour is dependent upon the magnitude of the difference between the silver deposits under each of the three sets of elementary colour filters, this evening out is a desaturating effect tending to destroy colour, and an increase in exposure when printing will do nothing to restore the lost colour.

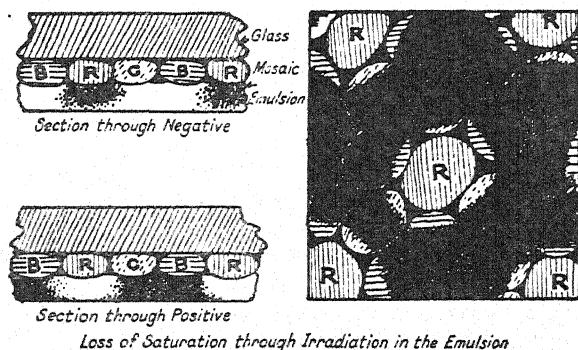
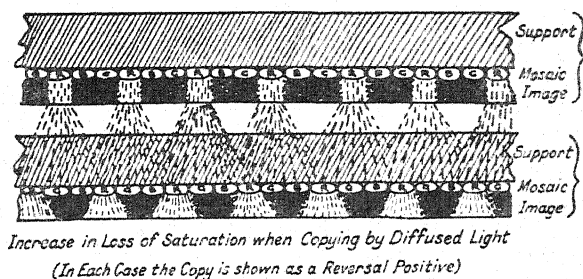


FIG. 167A.—Causes of loss of saturation when one mosaic image is printed upon another (Spencer).

Furthermore, the scattering which occurs only once in the reversal processing of a camera exposure, and which is largely counteracted by the colour contrast effect, operates twice in negative-positive processing to produce an intolerable degradation of the colour rendering. Accordingly, to make negative-positive processing of combined screen material a practical proposition, the irradiation within the emulsion must be reduced to a minimum. Since the deeper the image extends into the emulsion the greater the irradiated area becomes, any technique which will confine the image to those layers of the emulsion nearest the *réseau* elements should minimize the scatter responsible for the degradation.

This has, in fact, proved to be the case, and the depth developer has been found to give results which are indistinguishable from reversal positive originals (D. A. Spencer, E.P. 470,855).

MONOCHROMATIC PRINTING LIGHT

Colour dilution may also be due to the spectral overlap in the transmissions of the colour elements of the *réseau*. This may be reduced to the minimum by restricting the printing light to three narrow wavelength groups corresponding as closely as possible to the maximum transmission of the three *réseau* colours. It is possible to print with three tungsten filament lamps used in conjunction with narrow-cut filters, the light being combined on the printing plane, but a more elegant arrangement was made possible by the advent of high-pressure mercury discharge lamps. Such a lamp is used in conjunction with a tungsten filament "Class A1" projector lamp of 500 watts which is filtered with a glass having narrow-cut transmission in the red region of the spectrum. This lamp is housed behind the mercury discharge lamp, the red light being completely diffused with a sheet of flashed opal glass. The mercury lamp has a very powerful line emission at $577\text{ M}\mu$, which is at an unfortunate position where the overlap in the Dufaycolor red and green elements is at its maximum. Happily, a saturated solution of didymium chloride completely absorbs this line, while still transmitting the valuable emission at $546\text{ M}\mu$ (green), which is ideally placed. The mixed light of the mercury and tungsten sources after passing through a cell of didymium chloride (didymium glass is almost equally effective) consists of three monochromatic bands whose wavelengths are

$670\text{ M}\mu^1$ — $605\text{ M}\mu$ (red),
 $546\text{ M}\mu$ (green),
 $436\text{ M}\mu$ (blue)

(with certain other faint lines).

This trichromatic monochromatic light prevents each primary colour element of the film-mosaic from transmitting light which has originated from the other two elements. The ideal is that light originating from one colour negative element, say red, should be totally absorbed by the green and blue positive elements, and this is realized in the above arrangement.

REMOVAL OF MOIRÉ²

The Dufaycolor negative record consists of silver densities variously distributed over the *réseau*, the particular distribution determining the colour seen by transmitted light. For example, if the silver densities are distributed so that they occur only on the red elements, the negative will appear minus red (or blue-green) and will represent the photograph of a red object. The negative records the colours of the subject as comple-

¹ The sensitivity of the emulsion falls off rapidly at $650\text{ M}\mu$, so that the presence of light of longer wavelength is of little consequence.

² Reprinted from *The Photographic Journal*, Vol. 79 (May 1939), pp. 320-9, by kind permission of the Royal Photographic Society, G. B. Harrison, O.B.E., and R. G. Horner.

mentaries, that is to say, the colours reflected by the subject are absent from the negative, all other colours being present. If the negative is now used as the subject and photographed either by means of a camera or by simple contact, the colours present in the negative will be absent from the print. The print will therefore be correctly coloured. For example, if the subject is red the negative will be minus red or blue-green; the print will be minus blue-green or red. This comparatively simple procedure is, however, complicated by the fact that the negative, unlike the subject, is divided up into a regular pattern of three colour elements, and, as is well known when two similar patterns are placed together, interference shows itself in the form of *moiré*, which may be visible in the form of lines or squares hundreds of times larger than the dimensions of the element pattern and therefore clearly visible to the naked eye.

These *moiré* patterns in the special case of Dufaycolor are produced briefly as follows—the dark parts of the pattern are regions in which elements of one colour on the negative are positioned over elements of different colour on the positive, so that the light has to pass through two elements of different colour—e.g., red and green. The lighter parts of the *moiré* pattern are produced in regions where the elements of one colour on the negative coincide exactly with elements of the same colour on the positive. Such a combination obviously transmits more light than when the coincident elements are of different colour. Prints made under such conditions will show corresponding dark and light areas.

In order to eliminate *moiré* patterns it is necessary to do one of two things—either to arrange that the two *réseaux*, the negative and positive, coincide exactly at all points, or to destroy the identity of the negative *réseau* in some way such that the light falling on the positive *réseau* is perfectly uniform and is not divided up into small elements of different colour.

It is not possible to apply the former method of exact registration of the two *réseaux* because, apart from the extreme difficulty of effecting this registration with such small elements, shrinkage due to processing, etc., renders it impossible to ensure continuous registration over areas comparable with the size of a *ciné* picture.

It is well known that the *moiré* pattern produced when two *réseaux* are superimposed varies in size and character as the angle between the two *réseaux* is varied, and an angle can be found at which the pattern becomes almost invisible. The pattern is, however, still present, but is of very small size, and if printing were carried out under such conditions with no further precautions the effect on projection would be very unsatisfactory. It must be realized that the pattern is not only undesirable because it produces a visible pattern on the screen but because the black areas which do not transmit light will fail to blacken the colour elements which should be blackened and so cause an addition of white to the colour photographed. For example, if the colour photographed is green

the negative will transmit red and blue. In the part of the print where the red of the negative falls on the blue of the positive, and vice versa, the blue and red elements of the positive when finished will transmit light and the overall colour of this section will be white (since the green element of the print will transmit in any case).

It appears, therefore, that a suitable adjustment of the angle between the negative and positive films cannot eliminate moiré; all it can do is to render the pattern rather less startlingly visible than it would be if the angle were such that that pattern size was several millimetres wide on the film. This fact is made use of in the actual process because it is not possible to ensure complete absence of moiré all the time owing to small variations in film shrinkage and thickness which are beyond control, so the optimum angle between the *réseaux* is always used so that any small residual moiré pattern has less chance of making itself apparent.

From what has been said it will be apparent that the problem is to devise a method of destroying the identity of the negative *réseau* by the time the light reaches the positive *réseau*. In other words, to arrange that the positive *réseau* is uniformly illuminated. Or, to put it in yet another way, to ensure that the light that passes through the negative *réseau* is thoroughly mixed before it strikes the positive *réseau*.

If the two *réseaux* are in perfect contact, no mixing of the light can possibly take place, and it is therefore necessary to start by separating the two *réseaux*. This can readily be done by placing the negative and positive films front to back, or back to back, thus separating the *réseaux* by one or two base thicknesses as the case may be. For quite another reason, bound up with the desirability of arranging that the positive film is projected with the emulsion facing the screen as for black and white so that the sound track is correctly focused, the films are placed front to back and are thus separated by one thickness of base only (this must be the positive base so that the light passes through the positive *réseau* before striking the positive emulsion).

By using a source of light of finite size as opposed to a point source, the projected image of the negative *réseau* will be diffused, and by using an extended source of definite shape and size it is possible to diffuse the projected image of the negative *réseau* completely, whilst retaining the maximum possible definition.

Consider first a pinhole camera. The image produced by such a camera is a perfect projected image of the object; it has the same shape as the object and its size is simply related to the size of the object and the position of the pinhole (Fig. 168). The Dufaycolor *réseau* may be regarded as composed of a number of juxtaposed squares, each containing one red, one green, and one blue element (Fig. 169). The red lines are actually continuous, but we can regard them as divided up by imaginary lines as indicated in the figure; let d be the length of the side

of the square ($d = \frac{1}{20}$ mm.—0.05 mm. for 20-line *réseau*). Now consider a very small area of any one of the squares—a pinhole in fact; it does not matter what colour element it falls in. Let us denote this pinhole by A in Fig. 169; the rest of the *réseau* is considered black for the moment. In Fig. 170 a perspective sketch shows the effect of casting an

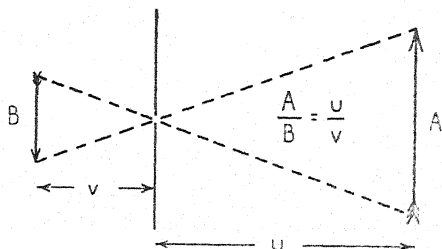


FIG. 168.

image of a square illuminated aperture by means of the pinhole A. As indicated in Fig. 168, by altering the size of the source or its distance we can make the image of the source any size we wish. Suppose we arrange that the image is a square having its sides parallel to the unit squares of

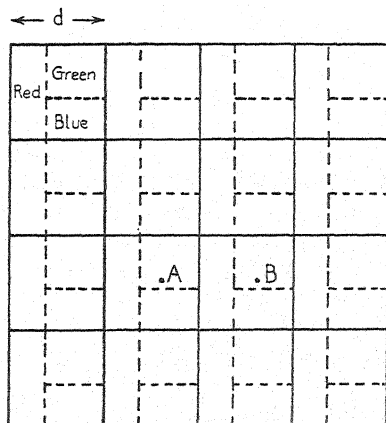


FIG. 169.

the *réseau* and equal to d . Now consider another pinhole B (Fig. 169) in an adjacent square, situated in exactly the same position relative to its square. The distance AB will be d . Under the same conditions the image cast by B will also be a square of side d , and the images of A and B will just touch, since $AB = d$. By imagining a similarly situated pinhole in every square, all providing images according to the same rule, the result will be perfectly uniform illumination on the screen. Now we

can further extend this to include another complete set of similarly situated pinholes but different from the AB set, and exactly the same arguments apply, until finally we have extended the pinholes until they cover the whole *réseau* surface, and we still have perfectly uniform illumination. It follows from the above argument that the illumination remains uniform if any part of the squares is rendered opaque, providing all squares are affected in the same way, so that if all the red elements are opaque the illumination, although changed in colour, remains uniform.

This, then, is the method¹ employed for destroying the identity of the negative *réseau* on the copy screen, and it only remains to find the formula relating to the various distances and sizes. Referring to Fig. 171, the negative *réseau* has been drawn as a pinhole because this leads to the necessary condition. The source is square and its side is D , and the condition of uniform illumination is that the projected image of this

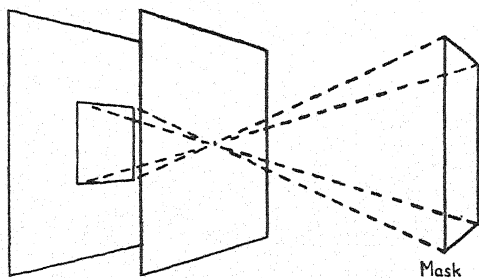


FIG. 170.

square source on the positive *réseau* is equal in size to the elementary square of the *negative réseau*—i.e., to the reciprocal of the number of lines per mm. (other dimensions must, then, be in mm.). It must be remembered, however, that in this case, although the true thickness of the base is, say, t , the effective optical thickness is $\frac{t}{\mu}$, where μ is the refractive index of the base (its value may be taken as 1.4).

From the geometry of the figure it is obvious (similar triangles) that

$$\frac{D}{T} = \frac{\mu d}{t},$$

where the letters denote distances as shown in Fig. 171. The values d , μ , and t are more or less fixed, so that ratio $\frac{D}{T}$ is fixed, but either D or T can be varied providing the other is adjusted to compensate. In practice it is desirable to make T fairly large, say 10 cm., otherwise parallax errors are introduced at the edges of the frame which might seriously affect the efficiency of the elimination of moiré at these places.

¹ See E.P. 446,679 (p. 176).

Taking a typical example, let $d=0.05$ mm. (20-line), $t=\frac{5}{1000}$ in. = 0.125 mm., $\mu=1.4$, and let us fix T at 10 cm. = 100 mm:

$$D = \frac{\mu d T}{t} = \frac{1.4 \times 0.05 \times 100}{0.125} = 56 \text{ mm.}$$

The side of the square source would under these conditions have to be 5.6 cm.

It is clear from what has been said that the sides of the square source must be parallel to the square *réseau* units, or in other words parallel to the red lines in the negative *réseau*. This accounts for the angle at which the square mask is set in the printer.

In practice the above formula may be used in designing printers, but it is always desirable to allow a little latitude in the position of the mask to allow adjustments to be made. It can be seen from the formula that

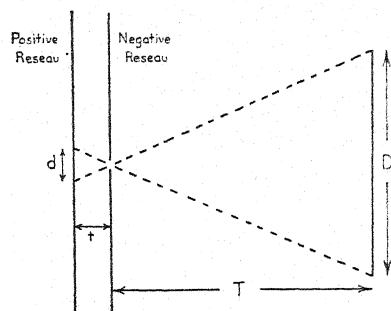


FIG. 171.

if the positive base thickness changes from 5 to $5\frac{1}{2}$ thousandths of an inch, the correct distance of the mask will change from 10 cm. to 11 cm. The difference in moiré between two such distances *can be detected*, and if the very best results are to be obtained the base thickness of the individual positive material being used should be allowed for. For all ordinary purposes, however, the distance may be set for the average positive thickness.

Finally, it is useful to make any final adjustments of distances by means of a test assembly. This consists of two pieces of film, one of which has been fixed out. The *réseau* side of the fixed-out film is cemented (secotine) to the base of the raw stock so that the red lines of the two *réseaux* are almost parallel and a large moiré pattern consisting of dark bands about 2 mm. apart is visible when the assembly is placed in front of a point source. The white emulsion layer of the raw stock acts as a perfectly diffusing translucent screen and so shows the pattern as it would be recorded on the emulsion. By placing this assembly in the gate of the printer the final adjustment of the mask position can be

readily determined as the position at which the pattern is least visible (it should disappear entirely at one position). If it is required to adjust the printer for a special print, a test assembly can be made in a few minutes,

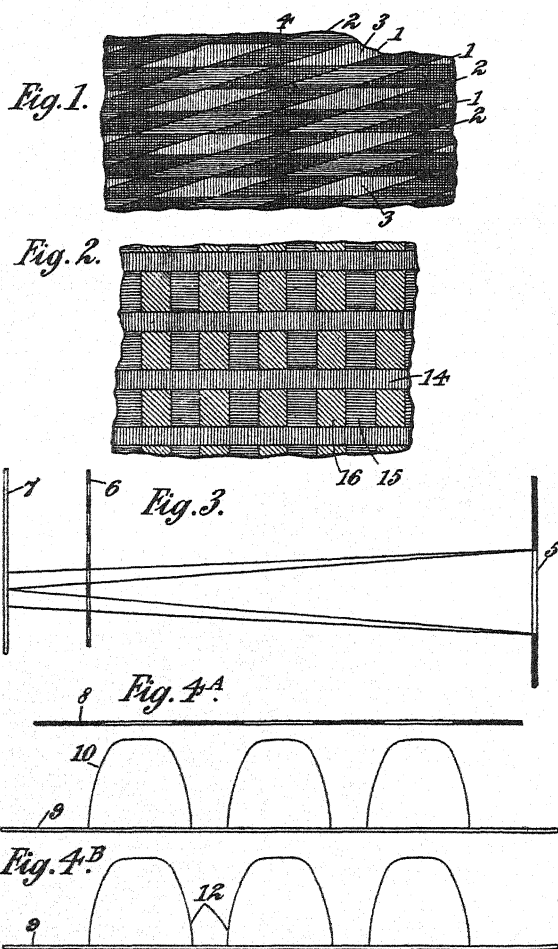
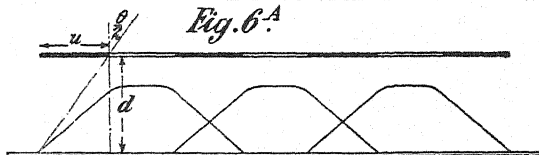
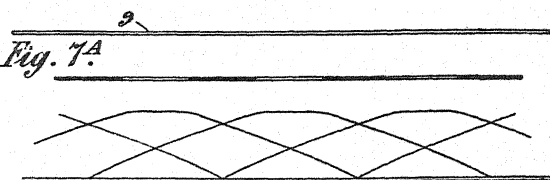
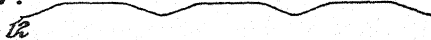
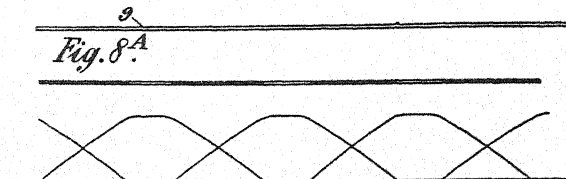


FIG. 172A.—EP. 446,679, 1934 (S. D. Threadgold).

using a sample of the positive stock to be used in the actual printing as the raw stock; any piece of plain *réseau* will do for the other piece (providing it has the same size *réseau* as the negative to be printed, e.g. 20-line, etc.). (Conclusion of quotation from Dr. Harrison's paper.)

TABLE 51

Base Thickness (mm.).	Distance of (56-mm.) Aperture in mm.
0.125	100
0.127	101
0.128	102
0.129	103
0.130	104
0.131	105
0.133	106
0.135	108
0.137	109
0.138	110
0.140	112

Fig. 5^A*Fig. 5^B**Fig. 6^A**Fig. 6^B**Fig. 7^A**Fig. 7^B**Fig. 8^A**Fig. 8^B*

E.P. 446,679

(Threadgold, S. D., 1934. See above, Dr. Harrison on removal of moiré.)

Records on regular pattern multicolour screen material are printed by contact on to similar material by means of a beam of diffused light from a source at which the cross-section of the beam is adjusted, according to the distance of the source from the screen associated with the original, the size of the screen elements, and the distance apart of the original and copy screens, to produce substantially uniform illumination of the copy screen. In Fig. 6A (see Fig. 172B), if μ is the distance on either side of an element of the copy screen over which the light is to be spread and d is the separation of the original and copy screens, the angle θ subtended by the source at any point of the original screen is given by the formula $\theta = 2 \tan^{-1} \mu/d$. In Fig. 3 (see Fig. 172A), light passing through the aperture 5 in a mask and through the elements of one colour (*e.g.*, red) in the original screen 6 falls on the copy screen 7 and is spread thereover; light passing the elements of each other colour of a three-colour screen comprising red stripes and stripes formed of alternate blue and green squares, the dimensions of the light-source, is calculated to give the desired spread in each direction for the red lines, the spread of the green and blue elements being then slightly too great.

Printing Machines

The leading manufacturers of 35-mm. motion picture printing machines have adapted their standard printers to Dufaycolor. For example, W. Vinten Ltd. follow normal practice as far as mechanical design is concerned.

The general principles of copying film by the Vinten-Dufaycolor printer are the same as those obtaining in most modern rotary contact film printing machines. The negative and positive are brought from their respective take-offs and come together on a curved gate incorporating an exposure slit. The positive film passes over a constant-friction sprocket. The two films, after leaving the gate, pass over a common sprocket which is driven through a mechanical filter. The tension obtained between the driven sprocket and the friction sprocket maintains the two films in close contact with the exposure slot in the gate. After leaving the driven sprocket the picture negative is taken up on the spool. The positive material with the picture printed on it then passes to a second printing head, where it comes into contact with a sound negative, and eventually the "married" print is spooled up at the end of the machine. The two heads may be used either simultaneously or independently of one another. The sound head may be used for printing ordinary black-and-white stock if necessary (Fig. 173).

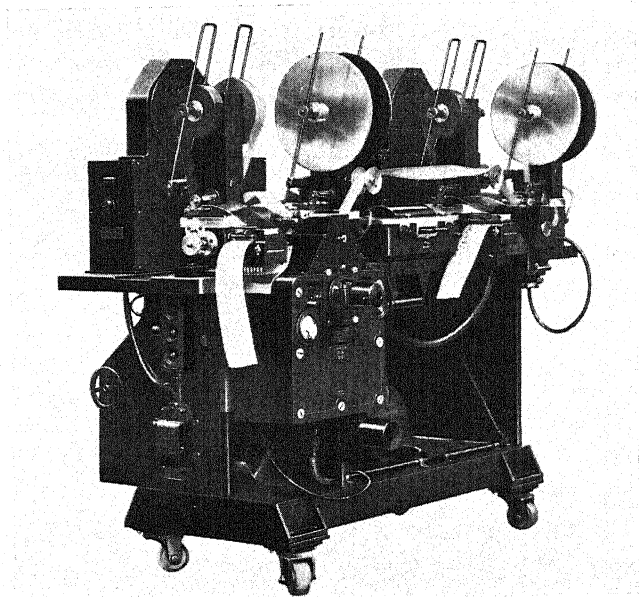


FIG. 173A.—Vinten-Dufaycolor 35-mm. film combined sound and picture printing machine (continuous type).

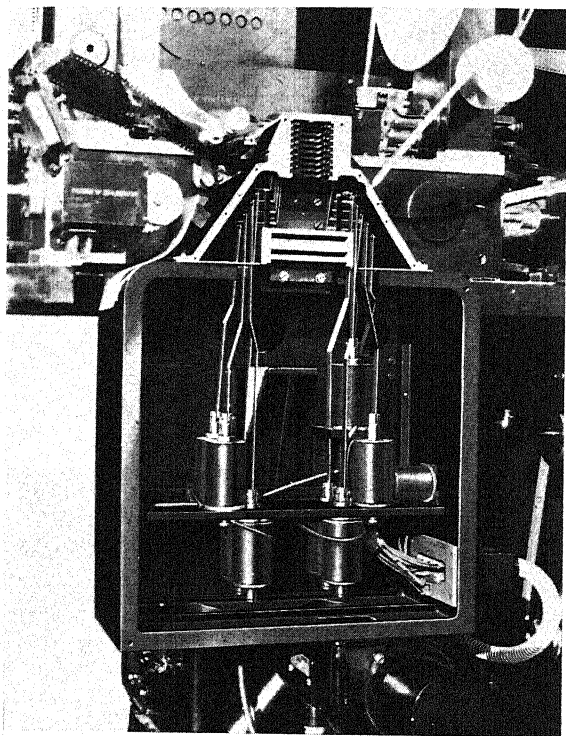


FIG. 175.—Vinten-Dufaycolor 35-mm. film printer, filter colour compensation unit, showing the solenoids and filter slots.

Light-Source

The light used for printing Dufaycolor consists of a 500-watt tungsten lamp, the light from which passes through a narrow-cut Chromex 523 laminated glass filter on to a prism (Fig. 173B). The prism turns the red beam through an angle of 90° and passes it through the arc of a 400-watt mercury high-pressure discharge tube. The combined light from the two lamps is now taken through a liquid didymium-chloride filter.

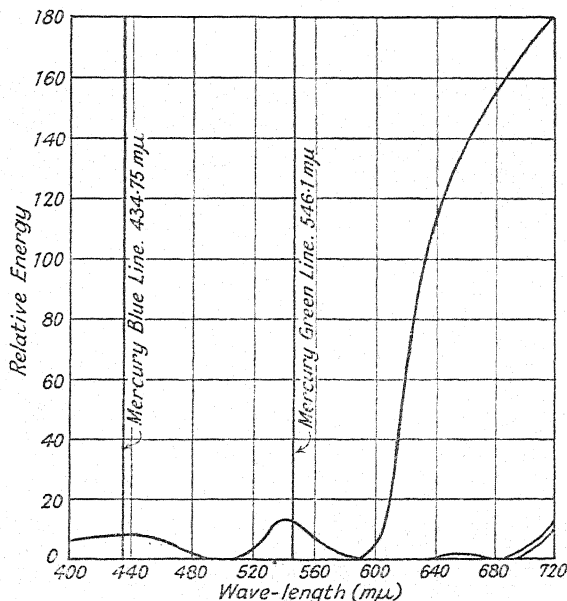


FIG. 173B.—Energy Distribution of Light from half-watt source (Illuminant A) filtered by a Standard Narrow Cut Red (Chromex 523).

Above the didymium-chloride cell¹ is a sliding filter holder for a compensating filter which incorporates the Harrison aperture of special form and dimensions (Fig. 174).

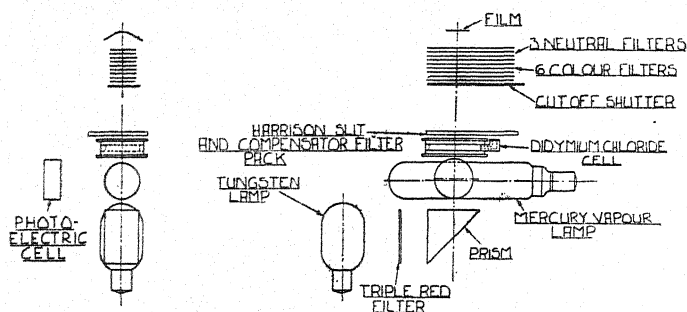
Light Control

The printing light is under control both for (a) intensity and (b) colour. In the case of (a) there are three neutral filters of different densities mounted in slides which are inserted into the light track automatically (Fig. 175). In the case of (b) there are six colour filters in similar slide mountings. These slides are operated by solenoids, which in turn are controlled through the well-known synchronously moving band principle, which operates as follows: The negative to be

¹ Didymium glass is equally effective. (Corning No. 5120 or Chance ON 16.)

COLOUR CINEMATOGRAPHY

printed is placed on the grading machine, and this punches a parchment band, 70 mm. wide, with the combination of light intensity and colour correction which is required. As the negative is wound through the grading machine so the paper band moves in a ratio of 1 : 100 with the negative, and at each requisite change of light the chart is punched accordingly. This method obviates any mutilation or damage to the negative, and the chart, once punched, will last for the printing of 100 copies. When printing, the chart is placed on the machine and the negative laced with its synchronizing mark at the printer gate. On starting the machine, the light changes come into action at the point determined on the grader; the whole process from then on is fully automatic. The light for the sound printing head is a normal 100-watt tungsten lamp.



DIAGRAMATIC LAYOUT OF
DUFAYCOLOR PRINTER

Fig. 174.

Photometric Light Control fitted to Vinten-Dufaycolor Printers

In practice it has been found that the mercury vapour lamp forming part of the Dufaycolor light-source is inclined to vary in emission. The object of the photometric control is to enable the printer operator to check the light emission from the mercury vapour lamp during printing. The apparatus consists of a photronic cell mounted integrally with the printer lamp-house, and a micro-ammeter in circuit with this cell. A hand-wheel control resistance in the mercury vapour lamp circuit is also part of the system. The use of the apparatus is as follows: At any time the operator pulls out a knob on the front of the lamp-house, this section opening a shutter which exposes the photronic cell to the light of the mercury vapour, thus causing a current to pass through the micro-ammeter. The latter instrument then shows the emission of the lamp, and if any variations occur from the predetermined setting the variations are compensated for by the use of the wheel control on the lamp resistance.

Colour Grading. Dufaycolor Negative-Positive

Dufaycolor printing is effected by light consisting essentially of three monochromatic bands, and the colour control is obtained by means of three sets of compensating filters each designed to reduce the intensity of one of the bands without affecting the others.

These filters, which are magenta, cyan (blue-green), and yellow in colour, are made in an arbitrary series of depths numbered 1, 2, 4, and 8, and these may be added together in combinations to obtain any desired intermediate value. Thus Magenta 4, Magenta 1, Cyan 1, Yellow 2, Yellow 1 might be used, and these would be referred to as a setting of 5-1-3.

The action of these filters on the print is to increase the complementary colour as each filter is increased in depth, and this may be worked out from first principles thus:

Suppose the yellow filter to be increased in depth, this will decrease the blue printing light and decrease the silver deposit under the blue squares of the *réseau*, leaving the red and green elements unchanged. This will increase the blue on the print, and in a similar manner an increase in depth of the magenta filter will produce a greener and, in the case of the cyan filter, a redder print.

The first step in producing a print is the choice of a representative shot or shots for test. These shots should be chosen to contain a good variety of colours, especially light desaturated tints and neutrals, as these are far more affected by colour correction than more saturated colours; and after printing at a trial setting, or in cases of doubt at a range of settings, they are processed normally and allowed to dry before examination, as otherwise parallax difficulties will arise, due to swollen gelatine.

On viewing either by daylight or preferably by a good artificial daylight, colour corrections may be applied either by first principles or by the use of Table 52, an increase in the filter in each case meaning an increase in the depth or number on the arbitrary scale.

TABLE 52

<i>Change made in Filters.</i>	<i>Effect on Print Colour.</i>
Increase depth of MAGENTA .. (Minus Green)	Increase of GREEN
Increase depth of CYAN .. (Minus Red)	Increase of RED
Increase depth of YELLOW .. (Minus Blue)	Increase of BLUE
Decrease depth of MAGENTA .. (Minus Green)	Increase of RED and BLUE
Decrease depth of CYAN .. (Minus Red)	Increase of BLUE and GREEN
Decrease depth of YELLOW .. (Minus Blue)	Increase of RED and GREEN (This is equal to an increase of Yellow or decrease of Blue.)

COLOUR CINEMATOGRAPHY

In certain cases it may be desired to decrease a particular filter by more than there is actually present at the time—*e.g.*, to make a print which had been made at 2.1.0 more yellow—and this may be done by increasing both the other filters together, since if we decrease both the red and green printing lights we shall relatively increase the blue. It follows from this that it is never necessary to use all three types of filter together, as any one may be replaced by a reduction in the other two. As a matter of convenience in the present machine a small amount of magenta filter is usually retained in order to avoid changing two filters at once.

Two points of practical importance are, firstly, an increase in filters implies a decrease in total light available, and the neutral grading should be increased by one point for each two filter points; secondly, the magenta filters are not as effective as the cyan or yellow and two points of magenta are approximately equivalent to one point of cyan or yellow.

The final test of any film must necessarily be on the screen, but by using daylight or a good artificial daylight for viewing, and in particular by always using the same light, it will be found that a very good idea of the colour balance can be obtained.

Compensating Filters

It is undoubtedly bad practice to use a large number of gelatine filters between the printing mask and the film. The number, except under exceptional circumstances, should be kept down to two or at the most three. When a number of gelatines are placed together they always appear "milky" and scatter light to a greater or less extent according to their freedom from manipulation scratches. Filters that become scratched should be discarded immediately.

The size and position of the printing mask are accurately determined, and any scatter introduced between the mask and the film will cause a change in the *apparent* size of the mask as seen from the film and also modify the distribution of the light. The greater the diffusion or the nearer the diffusing medium to the film the greater will be the disturbance to the illuminating system. The effect is roughly analogous to the introduction of a diffusing filter into a camera between the lens and the film, in this case the nearer the filter to the lens the greater the disturbance of the image.

The result of using filters which diffuse the light between the mask and the film in the printer will be to cause loss of definition and loss of contrast. Loss of definition results from the effective size of the mask being increased, and loss of contrast will be due to light entering obliquely through the negative *réseau* being reflected several times between the negative and positive *réseau* and causing a general spread of light which

is making no contribution to the image proper. This will approximate the result which would be obtained by giving a uniform flash exposure to the positive film before processing, a procedure which would cause fog and loss of contrast. The final result will be that exposures will be so adjusted as to give clear whites, in which case blacks will have a low density, and a soft print with low maximum black will be obtained. A

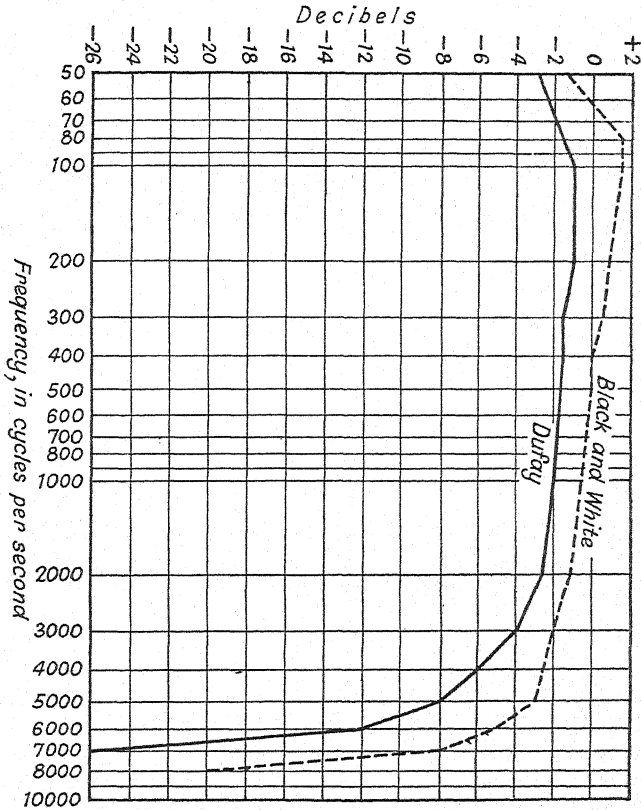


FIG. 176.—Black-and-white and Dufaycolor comparative frequency response.

further undesirable consequence of using diffusing filters will be that the system will no longer eliminate moiré as it was designed to do, though in practice this will probably not be apparent.

The loss of definition and contrast is a very real effect, and precautions should be taken to employ the minimum diffusion between the mask and the film in the same way that no good cameraman would use a dirty or scratched filter on his camera. The use of a large number of filters can readily be overcome by having available a sufficient range of

the necessary colours. It is then theoretically never necessary to use more than two filters at a time, but allowing for practical difficulties which may arise occasionally, allowance for three filters at a time should be ample.

Sound Reproduction

Taking the distance apart of the red lines on the *réseau* set at an angle of 23° —0.05 mm.—and assuming a 450-mm. speed per second, we get 9,000 cycles, at which a slight sound might be given. This is comparable to 0.15 in variable density, and is not serious. There is a loss of about $1\frac{1}{2}$ db. in output, which is negligible, and a slight increase in the loss from 3,000 cycles upwards (Fig. 176).

Variable density track has to be printed with red light owing to the lack of penetration in the case of printing with blue light. The very advantages which are given by reduction of scatter and surface printing with blue or ultra-violet light are negated by the effect of the hypo-developer, which is active on the surface first of all. With red light maximum penetration is obtained. Excellent variable area tracks are printed, since the definition is actually improved by the depth development. The conditions in so far as gamma is concerned are much the same as in normal black-and-white practice. Positive is generally developed to a gamma of 1.80-2.00. Density of unmodulated track is 0.60 (*réseau* density taken as zero).

The sound track is printed on the emulsion side of the film by a normal sound-printing machine. Sound track has been quite successfully recorded on Dufaycolor *negative*. Even when recorded *through* the *réseau*, the quality is good enough for news films.

Camera

Dufaycolor film may be exposed in all existing cameras. There are, however, one or two minor refinements which must be attended to in order to obtain perfect results. First of all, since the picture has to be exposed through the *réseau*, it follows that the emulsion is turned away from the lens and the image is therefore formed on a plane which is behind the normal, a distance equivalent to the thickness of the base. Taking the refractive index of the base into consideration this distance should be four thousandths of an inch further back. The manufacturer can re-scale the lens, and similarly he can, in cameras such as the Vinten or the Sinclair, adjust the ground-glass focusing screen. Alternatively, any competent operator can determine a new infinity point on his existing scale by photographic test, and, placing an arrow at this point, all other distances marked on the scale will be correct when brought opposite the new arrow. This is a perfectly reliable empirical method. Refocusing is of importance for short-focus

lenses—say for any lens of less than 3 in. focus. Another method can be used for cameras which have means for looking directly through the film. Place a piece of Dufaycolor film in the gate, the lens being at full aperture. (It will be observed that it is easy to see the image as long as the object is illuminated by sunlight.) Focus the telescope of the eyepiece sharply on the *réseau pattern*, which can just be observed. Then focus the lens on infinity, always turning the focusing ring, or other control, in the same direction (coming on to infinity from a point beyond it). When the image is at its sharpest point it will be found that the position reached on the engraved scale is a little beyond the normal infinity mark. Engrave a point opposite the position found and proceed as instructed above. It is of interest to note that if one cannot see the image clearly through the film it is of little use to attempt exposure.

The fact that the emulsion is the opposite way round in the gate necessitates great care to avoid scratches. W. Vinten Ltd. recess the back element of the camera gate especially for work with Dufaycolor. The Bell & Howell Company polish the back of the Eyemo camera gate and burnish all metal parts which might come into contact with the film. Little trouble has been experienced with the Newman Sinclair camera, nor with the Debie. The rollers used for pressure in the Mitchell gate are perhaps rather dangerous. It has been suggested that it might be desirable to recess these rollers by a thousandth of an inch, in any case over the picture area, if not on the edges of the film. Undoubtedly special precautions should always be taken with Dufaycolor to be certain that the gate is perfectly clean and that no emulsion particles have adhered to any slide or pressure pad. The film should be frequently inspected between shots.

TWO TYPES OF NEGATIVE EMULSION AVAILABLE

Dufaycolor ciné film is made in two types, known as Type I.N. and Type I.G. The former is for work in daylight or high-intensity arcs, the latter is exclusively for photography by the light of incandescent filament lamps. Type I.N. has a daylight Weston rating of 6. The exposure Table 53 gives a rough idea of the aperture for various conditions in England in the summer.

Neither of these stocks requires a filter for their respective illuminants. Type I.G. is balanced for filament lamps of about 3,000° K. colour-temperature. On the other hand, Type I.N. Dufaycolor is balanced for sunlight, or for its equivalent, high-intensity arcs having a colour-temperature of 6,000° K.

For exterior work Dufaycolor technicians advise the use of an exposure meter such as the Weston Ciné Exposure Meter, with which the correct aperture may be read directly. This meter possesses the advantage of a small acceptance angle (approximately 25°) correspond-

TABLE 53.—EXPOSURE TABLE

	<i>Sunshine (White Clouds).</i>	<i>Sunshine (Blue Skies).</i>	<i>Slightly Overcast (Sun Visible through Light Clouds).</i>	<i>Com- pletely Overcast but Good Light.</i>	<i>Overcast and Dull.</i>
Distant buildings Wide streets Open situations }	<i>f/5-6</i>	<i>f/5</i>	<i>f/4</i>	<i>f/3</i>	<i>f/2.3 or max. available aperture</i>
Near views of houses (figures in middle distance)	<i>f/5</i>	<i>f/4.5</i>	<i>f/3.5</i>	<i>f/2.3</i>	<i>„</i>
Close-ups and groups	<i>f/4.5</i>	<i>f/4</i>	<i>f/3</i>	Full aperture	<i>„</i>

ing to that given by a 50-mm. ciné lens. Type I.N. emulsion has a fairly long straight-line response, but the user cannot expect a latitude equal to black-and-white emulsions. For this reason serious errors in exposure are not permissible. Over-exposure is much to be preferred to under-exposure. The limited scale forbids correct rendering of light values exceeding a scale of five to one. The object should always be to record every part of the subject on the straight-line part of the response, but in many situations this is impossible and a compromise must be made. Certainly extreme contrasts of light should be avoided unless a special effect is required.

I.G. stock has a somewhat longer scale than Type I.N., and it has shown itself capable of rendering the subtlest gradations of colour.

Artificial Lighting for Dufaycolor : Type I.N.

The makers strongly recommend that any production, the majority of sets of which exceed the dimension of, say, 20 ft. \times 15 ft., should be photographed on Type I.N. stock. It is essential that individual lamps emit light which is steady in quantity and quality. The colour-temperature of all the lamps on the set must be matched, and the distribution should be as even as it is possible to obtain. Hot spots must be avoided. The Mole-Richardson range of studio arc lamps meets all the required conditions. Earlier types of arc lamp sometimes found in studios in Europe are as a rule unsatisfactory, and are obsolete for colour photography. Such lamps are unsteady because they are hand fed and their colour-temperature is unmatched.

Tungsten filament lamps may be occasionally used with Type I.N. stock, but the wattage required is excessive. A Dufaycolor filter (T.D.) is available for raising the colour-temperature of the tungsten light to the equivalent of the high-intensity arcs, namely from 3,200° K. to 6,000° K.

The luminance levels required for I.N. stock, assuming a lens aperture of $f/2$, shutter at 170°, and 24 frames per second, will be:

Incident light {	Front lighting	650-750 foot-candles
	Highlights	750-1,000 " "
	Shadow areas	350-500 " "

Any part of the subject the luminance of which is less than 250 foot-candles will be underexposed.

Type I.G.

The principal requirement is that the tungsten filament lamps for which this stock is balanced must be carefully matched in colour-temperature. It is highly inadvisable to use old lamps. Studio projector lamps of high wattage should not be mixed with general service lamps which are rated differently and have a lower colour-temperature. It is impracticable to mix natural daylight or high-intensity arcs with "inkies." The lamps should be run at a colour-temperature of not less than 3,200° K. The luminance levels given above for arc lighting also apply to I.G. stock.

LOAD IN KILOWATTS REQUIRED FOR A GIVEN SET

As a rough indication of the load needed for Type I.G. stock to light a given set with tungsten filament lamps, the following formula will be found helpful:

- (1) Load in kilowatts = CD^2 ,

where D is the distance from the camera to the back of the set in feet.

- (2) Also load in kilowatts = $10.76 CD^2$,

where D is the distance from the camera to the back of the set in metres.

C in both formulæ is a constant for each lens; see table below:

Lens.	Constant C.
35 mm.	0.12
40 "	0.09
50 "	0.06
75 "	0.03

Make-up for Dufaycolor

The public in their judgment of the rightness of the colour quality of films are naturally prone to concentrate upon those colour tones with

which they suppose themselves to be most familiar, and perhaps there has been no objection more prominent than that the flesh colour is not right. The best result is achieved by the use of the absolute minimum of make-up, and it is quite certain that any woman, or for that matter any man, properly made up for Dufaycolor could be seen in the street without attracting undue attention.

There is no standard make-up to be obtained from one jar and applied to all complexions for colour cinematography. Each individual must be considered separately. There are two guiding factors for consideration:

1. The natural colouring of the individual, which must form the basis on which to work.
2. The type of character to be portrayed.

According to these factors are determined the amount of make-up and the actual tones of make-up used.

INSTRUCTIONS ON APPLICATION OF MAKE-UP

It is important that the light under which the colour make-up is done is daylight, or a good artificial daylight. Special glasses can be obtained on application to Dufay-Chromex for use by the make-up artist which will enable him to see his work exactly as it will appear on the screen. Max Factor make-up has proven satisfactory, and it should be used in accordance with the following instructions. A table of Max Factor shades is attached.

Applying Cake Make-up.—First clean the face with melting cream, and wipe clean with soft tissue. Pat on a tiny bit of skin freshener. Then moisten the sponge, squeezing out the surplus water. Rub sponge firmly over cake and apply to the face, beginning with the forehead. You can either wait for it to dry, or pat gently with soft tissue, which will hasten the drying process. Then brush over with a powder brush, and complete your make-up as usual. All areas of flesh visible to the camera must be made up in accordance with the individual make-up. It is important that this should be applied directly and evenly, and then brushed over. Quantity of pancake used is as required.

Applying Lining Colours.—Before applying, the lining colour should be softened with cream, reducing the present consistency about 50 per cent. Then apply by patting. Do not rub.

Powdering.—For colour make-up neutral tints only are used. Powders the same tone as the foundation are generally used. The purpose of powdering is to help the texture of the skin, *i.e.* to give a matt surface, and it has nothing to do with the colour of the skin. In some cases little or no powder is required, *i.e.* for some characters a slightly greasy texture is preferable. Before applying the powder be sure that the make-up is thoroughly dry, then, with a powder brush, brush briskly to remove all surplus make-up. The brushing helps to smooth the entire surface

area, and also to remove any surplus amount which would ordinarily appear too heavy. Then powder by patting it over the entire area lightly, using about one-third of the usual amount that is used in comparison with grease-paint make-up. After you have powdered, again brush it with your powder brush—this time lightly.

Applying Rouge.—Dry rouge is the most satisfactory for females. The dry rouge for the cheeks is applied with a powder brush, and is blended so that there will be no demarcation on the edges. Grease rouge is better for males. This should be stippled on. Use only sufficient colour for street make-up. Watch the complexion carefully during shooting, since changes may occur.

Applying Lip Rouge.—Apply the lip rouge in the usual manner, but sparingly. There should only be enough lip rouge colouring to cover the natural lip pigment. If, in applying, there is a surplus of rouge on the lips, remove by inserting a tissue and impressing the lips on this tissue, which will absorb the excess quantity. Lip gloss used sparingly is advised. This helps to keep the lip rouge even in appearance, and prevents caking.

Applying Highlights and Shadows.—Whenever it is necessary to use highlights or shadows apply it to the areas before using the base colouring. In other words, the highlights and shadows are underneath the base make-up. The highlights or shadows can be applied with a water-colour brush. The brush is first moistened and then rubbed into the proper colouring of cake make-up, and then applied to the necessary areas. Have this thoroughly dry before applying the base make-up. The base make-up will not smudge the highlights or shadows.

Use of Grease-Paint.—Grease-paint is never used as the foundation in place of pancake for Dufaycolor. It can be used in certain cases for highlights, shadows, to cover scars, etc., but then only in very small quantities. The same range of tones is used as in pancake.

Sponges.—The selection of sponges is very important. Be sure to select a fine-grain sponge of a very soft silky texture, and if possible of the type that has not been bleached.

Artificial Eyelashes.—If required these can be used quite satisfactorily.

General Remarks.—A colour make-up is best an hour or two after application, when traces of noticeable artificiality disappear and the natural skin texture of the individual penetrates the make-up. The make-up has by that time become part of the individual. Usually a make-up will last for the whole day's work. It can be retouched and repaired as necessary.

The above outline applies to straight make-ups for colour cinematography. The same principles apply to character work: the more natural in appearance and colour these can be made to look the more satisfactory the result.

TABLE 54.—MAX FACTOR MAKE-UP FOR DUFAYCOLOR: SUGGESTED USES

<i>Women</i>					
For Normal Complexions	..	..	..	No. 21M Pancake	
For Drab and Yellow Complexions	..	..	..	No. 21L	„
For Brunettes—Very Fair Complexions	..	..	..	No. 21R	„
Sallow or Dark Complexions	..	..	..	No. 24G	„
For Blondes—Very Fair Complexions	..	..	..	No. 21R	„
For Highlights	..	..	..	No. 21P	„
For Shadowing	..	..	..	No. 24H	„
For Powdering	..	..	..	No. 1A Neutral Powder	
For Lips	..	..	..	Vermilion and Carmine Lipstick	
For Cheeks (Dry Rouge)	..	..	..	Carmine Rouge	
For Eyes	..	..	..	No. 6 Eye Lining	
<i>Men</i>					
For Normal Complexions	..	..	..	No. 24H Pancake	
For Very Dark Complexions	..	..	..	No. 24K-24L or 25HY Pancake	
For Fair Complexions	..	..	..	No. 24G	
For Shadowing	..	..	..	No. 25 HY	
For Highlights	..	..	..	No. 21M	
For Extreme Highlights	..	..	..	No. 21P	
For Powdering	..	..	..	No. 3A Neutral	

Negative Development

The various types of automatic developing machines found in modern processing laboratories are all suitable for the development of Dufaycolor negative. Tank machines are perhaps preferable to tubular, as the latter may cause "flow" marks. The time of development is short. In standard Vinten machines with the following formula the time is five minutes at 65° F. and development is carried to a gamma of 0.95 (see Fig. 177).

DUFAYCOLOR 35-MM. NEGATIVE DEVELOPER—FORMULA D.S.9

Metol	..	..	..	2.5 gm.	} A
Sodium Sulphite (Crystal)	..	..	..	12.5	
Thiosulphate (Hypo)	..	..	..	5	
Pot. Bromide	..	..	..	2.1	„
Dissolve A in 500 c.c. of water.					
Sodium Hydroxide (Caustic Soda)	..	..	..	2.5 gm.—B	
Dissolve B in 500 c.c. of water.					
Take equal parts of A and B.					

Solutions A and B keep well separately. When mixed the life of the developer is short. A 24-gallon tank will develop 5,000 ft. of film, and it should then be thrown away. The developer is not very costly to make up, otherwise the rapid deterioration of the bath would be a serious defect from the laboratory costing aspect.

Projection.—Normal. But Dufaycolor film cannot be properly appreciated in theatres equipped with light-sources which are in-

adequate for black and white; and this can be said, unfortunately, of many British theatres. Since the *réseau* is responsible for the absorption of at least 70 per cent. of the light, it follows that in whatever theatre the film is shown the whites of the picture are only 25 per cent. as light as normally. This would unquestionably be very serious were it not for the adaptation powers of the eye. Even so, if we conclude that the average luminance of the screen in the larger theatres is 7 foot-lamberts, then the screen luminance for clear Dufaycolor *réseau* will be only 1.7 foot-lamberts. Therefore it is highly desirable that Dufaycolor film should be projected with the maximum light.

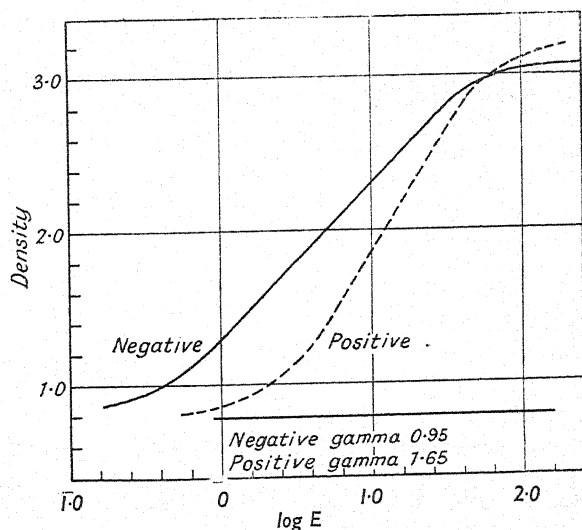


FIG. 177.—Characteristic curve of Dufaycolor 35 mm. Negative Film.

Remarks.—No colour process can claim all qualities, and Dufaycolor has many points in its favour. It is a straightforward negative-positive process; thus the analysis and synthesis is reduced to a purely photographic operation with the minimum chance for defects to arise during a series of difficult transformations. The colour range is all that could be desired, delicate tones being rendered with great beauty. As a technical achievement in manufacture nothing more remarkable has been done in the history of photography. Had the whole project been put before experienced photographic manufacturers in the first place, it would probably have been rejected as chimerical. It could only have reached the present stage of practicability by the untiring belief and support of private individuals determined, in spite of endless obstacles and the prospect of almost certain failure, to solve the prodigious problems involved.

Dufaycolor 16-mm. Reversal Film

Instructions.—The camera should be threaded in the usual way, but the glossy side of the film must face the lens. There is a metal band around the spool to protect the film from unwanted light during loading. Do not remove this until the last possible moment. *But do not forget to remove it.* Loading and unloading should be carried out in a shaded place.

Colour Filter.—No filter is required for daylight photography. Filters are supplied by the makers for various types of tungsten filament lamps.

TABLE 55.—EXPOSURES IN SUNSHINE IN BRITISH ISLES AND SIMILAR LATITUDES

Time of Year	April, May, June, July, and August.		February, March, September, and October.		January, November, and December.	
	Time of day	11-3 (8-10) (4-7)	12-2 (9-11) (3-5)	11-30- 12-30 (10-11) (1-2)		
Sea and sky, open landscape and beach scenes	<i>f</i> /11	<i>f</i> /8	<i>f</i> /8	<i>f</i> /5-6	<i>f</i> /5-6	<i>f</i> /4-5
Light foreground or river scenes	<i>f</i> /8	<i>f</i> /5-6	<i>f</i> /5-6	<i>f</i> /4-5	<i>f</i> /4-5	<i>f</i> /3-5
Street scenes, foliage and near buildings, groups out of doors	<i>f</i> /5-6	<i>f</i> /4-5	<i>f</i> /4-5	<i>f</i> /3-5	<i>f</i> /3-5	<i>f</i> /2-8
Narrow streets	<i>f</i> /4-5	<i>f</i> /3-5	<i>f</i> /3-5	<i>f</i> /2-8	<i>f</i> /2-8	<i>f</i> /1-9
Woodland glades	<i>f</i> /3-5	<i>f</i> /2-5	<i>f</i> /2-5	<i>f</i> /1-9	<i>f</i> /1-9	Too dark

When sun is obscured open up one stop (e.g., from *f*/8 to *f*/5-6). Slight over-exposure is preferable to under-exposure. When in doubt between two apertures use the larger.

Exposure.—Correct exposure is, needless to say, essential. A reliable exposure meter should be used, such as the Weston, Model 819. A general indication of the exposures required is contained in Table 55.

Table 56 gives the speed ratings for Dufaycolor reversal film given by the more commonly known still and ciné exposure meters.

Projection.—With the ordinary home projector a picture 2 ft. 6 in. × 1 ft. 8 in. is a suitable size to show. Larger pictures tend to emphasize the pattern of the screen mosaic. It is advisable to use a 3-in. projection lens. Do not use too much light. A powerful projector is needed only when it is required to show a picture several feet wide.

TABLE 56

<i>Exposure Meters.</i>					<i>Daylight Speed.</i>
A.S.A. .. .. .	..	..	..	..	8
Avo .. .. .	..	..	..	..	400 H. & D.
Avo-Smethurst Highlight .. ..	..	..	..	..	7
					(Half-watt 1)
					(Photoflood 2½)
Blendux .. .. .	..	..	..	..	17 or Class C
Bewi .. .. .	..	..	..	..	17° Scheiner
Electrodrem .. .. .	..	..	..	..	24° "
G.E. .. .. .	..	..	..	..	10
Helios .. .. .	..	..	..	..	20° "
Ilford .. .. .	..	..	..	..	Group C
Leicameter .. .. .	..	..	..	..	17° Weston Scheiner
Metrovick .. .. .	..	..	..	..	20° Scheiner
Ombrux .. .. .	..	..	..	..	17° "
Photoscop .. .. .	..	..	..	..	17° "
Prinsen .. .. .	..	..	..	..	400 H. & D.
Sixtus .. .. .	..	..	..	..	15/10 DIN in full sunlight
					9/10 DIN other exposures and
					indoors
Tempiphot .. .. .	..	..	..	..	19° Scheiner
Weston .. .. .	..	..	..	..	6
<i>Extinction Meters.</i>					
Leudi .. .. .	..	..	..	..	22° Scheiner
Justophot .. .. .	..	..	..	..	16-19° Scheiner
Justodrem .. .. .	..	..	..	..	20-23° "
<i>Sensitive Paper Meters.</i>					
Wynne's Infallible	f/78
Watkin's Bee	65
<i>Calculator.</i>					
Burroughs-Wellcome	½

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CERTAIN DUFAYCOLOR PATENTS

E.P. 217,557	1925	Four-colour screen.
E.P. 243,932	1925	Triplex film. Acetate between nitrocellulose.
E.P. 262,386	1927	Two separate layers. For stills.
E.P. 279,139	1927	New plasticizers such as hexachloropropane.
E.P. 281,803	1927	Double casting of base.
E.P. 282,980	1928	Opaque cellulose material.
E.P. 287,635	1928	Evaporation of solvents.
E.P. 294,008	1928	New plasticizers such as di-phenyl-di-cresyl-phosphate.
E.P. 301,439	1928	To reduce static charge. Apparatus therefor.
E.P. 307,437	1929	Printing on red, yellow, and blue screen.
E.P. 321,222	1929	Special meniscus coating machine.
E.P. 322,432	1929	The screen as now made on cellulose acetate.
E.P. 322,433	1929	Angle of lines of screen.
E.P. 322,454	1929	Printing machine for <i>réseau</i> .
E.P. 324,043	1930	Intensification of the original. Dilution of colour in copy avoided by pure hues in original screen.
E.P. 333,865	1930	Treatment of surface with alkaline reagent such as caustic potash previous to dyeing.
E.P. 334,243	1930	Inclusion of dye in ink resist.
E.P. 334,265	1930	Surface layer of cellulose acetate.
E.P. 335,899	1930	Sound record track for <i>réseau</i> film.
E.P. 337,040	1930	Stripping positives for opaque printing.
E.P. 337,073	1930	Isolation coating between cel. acetate base and collodion to avoid dissolving dyes in <i>réseau</i> .
E.P. 339,238	1930	Application of dyes in non-penetrative state. Powder or castor oil.
E.P. 417,860	1933	Printing with spectrum beam.
E.P. 434,434	1934	Duplication of master negative.
E.P. 437,888	1934	Printing. Multiple source.
E.P. 446,679	1934	Printing aperture. For elimination of moiré.
E.P. 448,264	1934	Printing apparatus. Diffusion of screen elements.
E.P. 444,773	1935	Three-colour prints.
E.P. 451,243	1935	Paper prints from Dufaycolor original transparencies.
E.P. 471,586	1935	Printing.
E.P. 470,855	1936	Depth developer for negative-positive processing.
E.P. 611,083	1946	Bitumen coating.
E.P. 611,094	1946	Bleach curtain.
E.P. 611,095	1946	Acid stop bath.
E.P. 611,096	1946	Hot box.
E.P. 611,097	1946	Degreasing.
E.P. 614,461	1946	Adaptable rollers.
U.S.P. 1,805,361	1931	

THE LENTICULAR PROCESS

Involving Specially Adjusted Filter Unit for Camera and Projector

Like all screen processes, this process depends upon the power of the eye to integrate the colour sensations derived from minute areas of coloured light of various hues. Individual elements consisting of primary colours blend into a single sensation at a distance which is determined by the resolving power of the eye. Such a process is evidently rightly classified as additive.¹

The lenticular process is, then, a screen process in principle, but the screen is formed entirely by optical means, the colour filter elements being placed in the lens system and the screen image formed as an image by microscopic optical elements embossed upon the film base. Most physicists would consider the lenticular process as the most elegant solution of the problem of motion pictures in colour so far discovered. It must be agreed that there is something very pretty about the idea of making the film base itself provide part of the optical system. Yet with all its theoretical perfection this system has certain defects which must have been overlooked by the pioneers of the method and which still effectively prevent its commercial success; or, if the defects were realized then, there was undue optimism that they would soon be overcome—a very common fault with the pioneers of colour systems.

The best lenses in miniature cameras or ciné cameras have for, say, a focal length of 50 mm. a disc of confusion equal to $\frac{1}{800}$ in., or 0.05 mm. The lenticule is 0.02 mm. in width, and for accurate results the image should fall only on one lenticule. This is why out-of-focus and marginal images are very poorly portrayed in lenticular systems.

Friedman points out that insufficient justice has been done to some of the precursors of Berthon. This is true. Thus Lipmann first conceived the possibility of using a film material embossed with minute lenses (*Brit. Journ. Phot.*, 55, 1908, p. 192). The film was to be embossed with a honeycomb of microscopic lenses. And F. N. Lanchester, an English engineer of genius, first suggested the replacement of a coloured screen in contact with the emulsion by means of forming an image of a rectangular slit divided longitudinally by three filter bands of red, green, and blue. An image of the subject in terms of this slit will be recorded as a series of parallel lines of density relative to the colour of the light, and of course the sensitivity of the emulsion—an optical screen in effect. R. E. Liesegang was the first inventor to use a banded filter (*Brit. Journ. Phot.*, 43, 1896, p. 569).

¹ The smallest visual angle in which two distinct points may be observed is 60 seconds. Below this the two sensations fuse into one. The retinal image corresponding to this angle is 0.004 mm., nearly the diameter of a single rod or cone. The eye can see a spot of a diameter of $\frac{1}{800}$ in.

COLOUR CINEMATOGRAPHY

Lenticular film represents the physicist's solution of the problem of colour photography, but attractive though it is at first sight the process loses its charm when subjected to closer scrutiny. Owing to the impossibility of conforming to ideal geometry in the design of a lens, the lenticular process suffers from:

- A. Marginal rays which have excessive circle of confusion and are focused on more than one lenticule, with consequent colour errors such as desaturation.
- B. Necessity of using nearly maximum aperture, with resulting poor depth of field, the focus for many planes of the subject occurring in front of the focal plane and thus covering more than one lenticule. The effect of this error will be colour desaturation and parallax fringing.

These defects would, however, be largely avoided by the use of lenticular film as the projection positive only and printing upon it from a master monopack negative such as Ansco Color, Kodacolor, or Agfacolor could now provide. This is perfectly practicable in theory, but it involves the almost insurmountable drawback of necessitating special projection optics. I.G. (E.P. 392,987) patented the process of contact-printing three separation negatives (normal) placed in contact with the embossed side (film-base side) of the lenticular positive film. The exposing beam is given an angular divergence with respect to the lenticular axes such that the image will be formed in the correct zones behind each cylindrical lenticular element.

The first important patent was that of R. Berthon, a Frenchman distinguished in astronomical optics. The patent (E.P. 10,611, 1909) may thus be summarized: A three-colour screen is placed in the objective and a series of microscopic images of the *objective* are obtained on the negative, carrying on one side a panchromatic emulsion and on the other side lines on a transparent embossed, striated, or grained surface. When the screens in the objective are arranged as parallel slits the film is embossed with semicylindrical striated surfaces. The negative may be developed as a negative or positive and used for reproduction through the same objective. The screen may be replaced by one with complementary colours, depending upon whether a positive or a negative is used (Fig. 178).

An important feature of Berthon's patent was that the tricolour filter should be placed at such a distance in the cone of rays that three elements were included from any point on the sensitive surface.

A. Keller-Dorian patented the methods for embossing the film by passing it through two cylinders, one of which had its surface engraved with the pattern of the lenticulations, while the counter-roller was to have an elastic surface, the elasticity of which allows of varying the depth of the impressions from the engraved surface on the film and

consequently also the profiles of the refracting elements (E.P. 24,698, 1914).

In pre-war Germany the firms of Siemens and Halske of Berlin, Perutz of Munich, and I.G. Farbenindustrie were active in the technical development of the lenticular process. Opticolor Akt. Ges. was jointly formed by the above interests to handle the European exploitation. Some eighty patents had been granted to these interests during a period of three years. Yet the lenticular process is still in the developmental stage in spite of all this lavish expenditure of brains and money. It is now doubtful whether anything will ever come of it.

In 1925 the Eastman Kodak Company acquired the 16-mm. rights of the Berthon-Keller-Dorian patents, and in 1928 lenticular film was placed on the market under the trade name of Kodacolor. The following description of the process was given in a paper entitled "Processes of Photography in Natural Colours," by Glen E. Matthews, of Kodak Research Laboratories, Rochester, New York.

THE KODACOLOR PROCESS¹

Kodacolor is a three-colour additive process which realizes the principle of a line screen method without the added difficulty of ruling a screen on the film support. The process is based on a means of impressing a series of microscopic cylindrical lenses into and across the support side of panchromatic film (Figs. 179, 182). A banded three-colour filter is fitted into a holder in front of the lens of the camera and projector. The film is threaded in the camera with the emulsion side away from the lens so that the light, before it reaches the sensitive emulsion, must be transmitted by the tiny embossed lenses, each one of which thus images the bands of the colour filter on the film. If the subject is white, all three colour filters allow light to pass and three lines are exposed under each lens element. If the subject is red, that is if it reflects red light, only the red parts of the filter transmit the light, and the emulsion areas illuminated by this section of the filter will be exposed. With colours that are made up of more than one primary it follows that more than one part of the tricolour filter will transmit the light.

Perhaps this may be made a little clearer if only one lens element and one colour of light, say blue, is considered as shown in Fig. 180. Here it is seen that the blue light exposes an area about one-third that under the lens element (No. 1). On development this area becomes opaque (No. 2). The film is then bleached, and the remaining silver salts are given a controlled exposure (No. 3) and developed up. Now the area affected by the blue light becomes clear and transparent, while the area corresponding to the red and green filter segments is opaque (No. 4). When white light is directed on this single lens section, it passes through the area where the blue light exposed the film; and since the optical system is reversible, it follows that the light will strike the blue segment of the filter and form a blue spot on the screen, since no light reaches either the green or red filter segments. In other words, all the tiny line areas transmit all, part, or no light, according as the subject reflects all, part, or none of the corresponding coloured light. The various colours are recombined on the screen to reproduce the natural colours of the subject photographed.

¹ The name "Kodacolor" was originally applied to the 16 mm. lenticular process as commercially exploited by Eastman Kodak. The lenticular process is now extinct, and the name was adopted for the negative multilayer roll-film.

COLOUR CINEMATOGRAPHY

Examination of an actual picture will make this principle clearer. Fig. 181 shows, on the left, a picture on Kodacolor film (actual size) of a child wearing a red hat. The child's head stands out in silhouette against a blue sky. In the enlargement on the right of one picture of the series the characteristic line composition of a Kodacolor

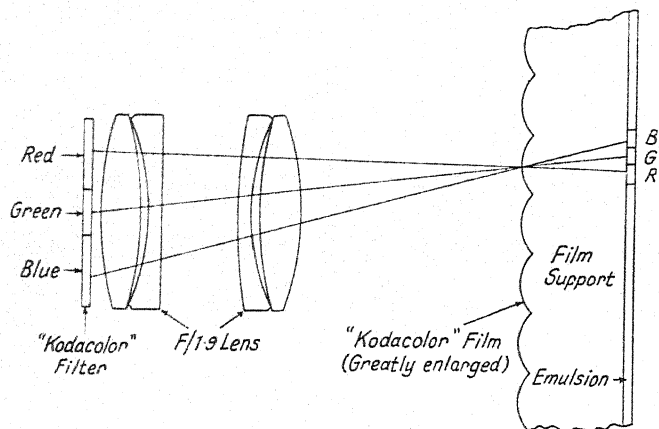


FIG. 179.

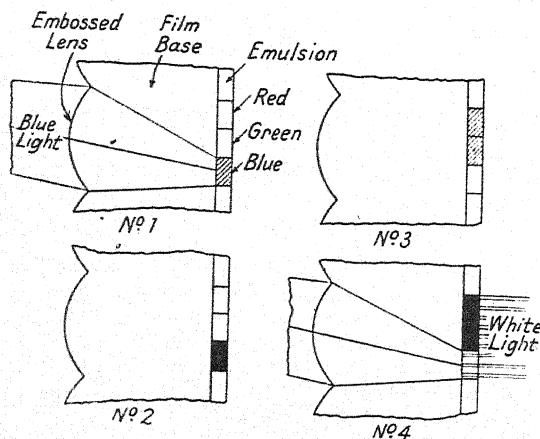


FIG. 180.

picture is readily discernible. Note that the lines are alternately dark and light where the red hat is reproduced (shown by arrow A), thus allowing light to pass through the image so that it will be transmitted only by the red part of the colour filter. In the area representing the blue sky the lines are dark and light, but they are displaced slightly from their position in the area of the red hat. This is best seen in the parts of the sky next to the hat (shown by arrow B). The sky area reproduces as blue on the screen, since only the blue part of the filter will receive and transmit light passing through that part of the picture.

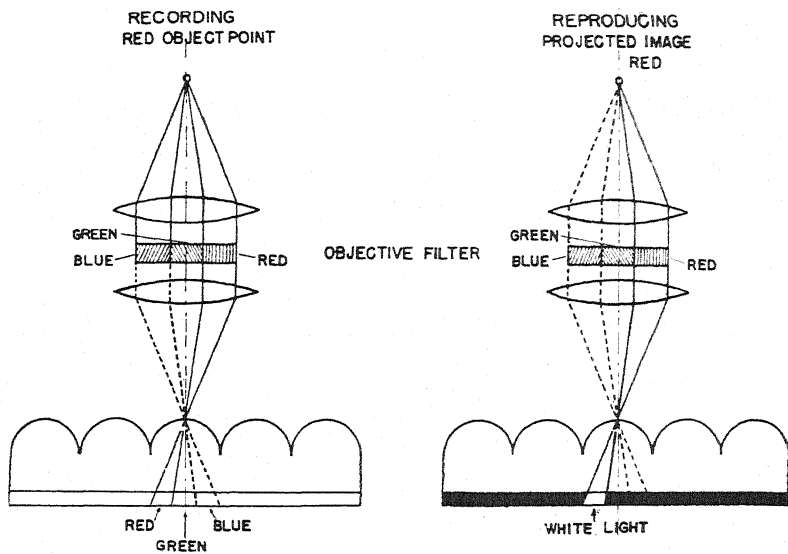


FIG. 178.—Principle of the Lenticular Process.



FIG. 181.—Kodacolor film, showing embossed surface. (Additive Kodacolor.)

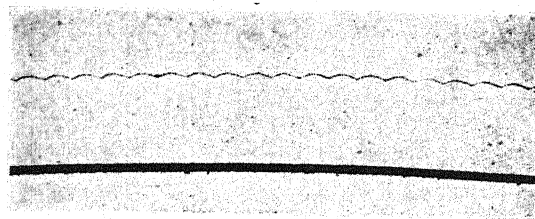


FIG. 182.—Photomicrograph of cross-section of Kodacolor film (thick black line is the emulsion).

THE AGFACOLOR LENTICULAR PROCESS. (Additive.) (Obsolete.)

At the risk of repeating ourselves, we give here extracts from a paper on the above process which makes very clear certain aspects of the lenticular process. The paper is by F. Weil under the title "The Optical-Photographic Principles of the Agfacolor Process" (a translation appeared in the *Journ. Soc. Mot. Pic. Eng.*, 20, No. 4, 1933).

Weil notes that the resolving power of the eye is a visual angle of one minute, corresponding to 0.02 mm. at the natural viewing distance.

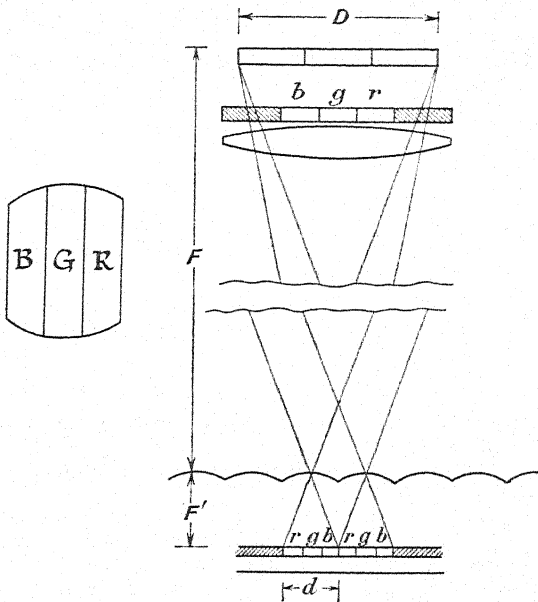


FIG. 183.

The width of each lenticule or embossing on the film is about 0.028 to 0.043 mm., the focal length being 0.10 to 0.14 mm.

The lenticular screen process as developed by Berthon solved the problem by very simple and ingenious means. Berthon abandoned from the very beginning the idea of attaching the filters, corresponding to the different surface elements, to the film (surface elements of a screen of the mosaic type), and of providing the film itself with a real colour screen. On the contrary, the screen is produced on the film optically during the exposure, and on the screen during projection. The film serves only as a support for an optical system of tiny cylindrical lenses embossed on the film base. The width of each lens is about 0.028 to 0.043 mm., the focal length being 0.1 to 0.14 mm. The lenticular screen is adjusted to the taking or projecting lens system, as shown in Fig. 183. A colour filter having three coloured areas, red, green and blue, in three parallel sections, is placed either inside or

outside the lens system. It does not matter where the filter is placed, so long as it controls the aperture. Furthermore, the filter diaphragm, or its virtual image, must not obscure the entrance pupil of the lens from any part of the film. The outer part of the filter would be so obscured, viewed from the margins of the film area. This defect will be more fully described later. Once the position has been fixed for exposing the film, this position becomes an inseparable characteristic of that particular film, and controls the true colour reproduction. The illustration shows the colour filter (RGB) placed in front of the lens, as occurs in practice. The virtual image appears at the distance F from the film, the width D representing the limiting diaphragm. Each of the cylindrical lenses embossed on the film produces a real, inverted, and reduced image of the tricolour filter in the focal plane of the embossed lenses, since the distance from the film to the filter, in comparison with the very short focal length of the embossed lenses, is practically infinite. The filter image replaces the grains of a mosaic screen, each image corresponding to one of the screen units. The maximum width is equal to the width of one embossed lens, and its length extends over the entire height of each picture, in the direction of the axis of the cylindrical lens. However, the units do not carry their own real three-colour screens, but look, so to speak, through telescopes to the one common colour screen, placed in the limiting diaphragm of the lens. The film itself appears colourless under ordinary observation.

The development is the same as in the colour screen process; *i.e.*, the original must be developed to a positive in order to obtain a direct reproduction in true colours. But while the screen positive itself contains the record of all colours, it is necessary to provide certain optical arrangements for projecting the lenticular films in colour. The simplest arrangement would be to use for projection the same lens as used in the camera, which would simply reverse the path of the exposing light. When lenses of other focal length and construction are used, care must be taken that the position and width of the colour filter appear, from the point of view of the lenticular screen, identical to their relations during exposure. It is only then that, at the given focal length of the lenticular elements, the position and width of the filter images behind the lenticular screen are identical to those of silver images formed by exposure and development of the film.

If the colour value of the projected image is to be at its best, the screen must satisfy certain requirements:

1. The real image of the filter as projected behind the lens elements must lie in the optical plane of the emulsion; the thickness of the film base and the focal length of the lens elements depend on each other. The focal length of the lenses in turn depends on the refractive index of the base and on the curvature of the lenses; hence the embossing of the screen must be done in a very particular way.

2. The real filter images behind the screen should cover the aperture of the lens elements in the same way as the filter covers the aperture of the camera lens. No light should be allowed to pass between the filter images, as the white light thus passing would weaken the colour. The size of the real filter image behind the screen is determined by the following simple optical relation: if, according to Fig. 183, D is the apparent width of the filter as viewed from the film, and F is the apparent distance of the filter, then F/D will be the aperture at which the filter appears when viewed from the film. If we call F' the focal length of the screen lenses and d the width of the real filter image, and n the refractive index of the film base, the following equation will result:

$$\frac{F'}{d} = \frac{nF}{D}$$

If the ratio FD is given by the focal length of the lens and the arrangement of the filter, then the maximum focal length of the lens element is limited, as the width of the filter image cannot be greater than the width of the cylindrical lens elements;

LENTICULAR PATENTS
(*British Patent Numbers*)

1909 ..	10,611	304,669	375,301	406,377	433,875	446,282	470,801
1913 ..	17,330	314,995	375,338	408,109	434,206	446,752	470,959
1914 ..	24,276	317,051	375,756	408,358	434,305	446,977	471,520
1914 ..	24,698	319,767	376,317	408,764	434,875	447,317	473,522
1915 ..	6,878	331,971	377,177	409,270	435,813	447,488	474,165
1915 ..	7,540	339,511	377,717	410,515	435,859	447,489	477,421
1915 ..	4,934	340,881	378,240	410,517	435,929	447,490	478,067
1921 ..	180,656	341,948	378,245	410,609	435,994	447,644	478,644
1923 ..	207,836	343,369	382,974	411,024	436,457	447,834	478,714
	207,837	349,267	383,263	411,407	436,465	447,917	480,123
	211,486	350,481	383,975	412,021	436,466	448,024	480,487
	236,204	353,121	383,976	414,079	436,587	449,762	480,546
	245,118	353,579	384,009	416,602	436,608	449,954	482,068
	246,829	354,167	384,275	417,020	436,871	451,175	482,690
	247,168	356,701	385,431	417,096	438,356	451,283	483,319
	261,363	356,977	385,680	418,040	438,448	451,347	484,797
	262,466	358,643	387,159	421,084	438,740	451,658	486,424
	264,123	359,474	388,062	421,120	438,748	451,659	486,495
	265,069	360,524	389,830	421,582	439,947	454,085	486,496
	272,191	362,490	391,110	422,017	440,025	454,163	486,839
	274,848	363,387	392,987	422,983	440,049	454,357	486,916
	279,837	363,409	394,305	422,991	440,187	454,842	487,685
	284,995	363,447	395,124	424,799	440,273	455,220	488,398
	285,035	364,559	395,200	424,906	440,300	456,617	489,185
	286,684	364,627	397,832	424,950	440,356	457,278	489,355
	287,488	365,108	399,379	424,951	440,567	457,656	489,529
	289,864	366,175	399,977	425,058	440,582	458,418	489,823
	289,886	367,411	399,984	428,366	440,809	459,027	492,850
	294,493	367,414	400,057	428,875	441,028	459,634	493,308
	294,579	368,970	401,963	429,121	441,709	460,533	493,804
	297,773	369,262	401,982	429,211	441,713	460,653	494,456
	298,242	371,546	402,384	430,467	442,522	461,559	495,100
	298,951	373,861	402,902	430,503	442,920	461,621	495,348
	301,732	373,938	406,013	430,585	443,266	462,794	497,753
	303,356	374,993	406,163	430,867	443,546	462,996	500,312
	303,357	375,225	406,187	432,401	444,191	464,723	503,909
	304,643	375,229	406,304	433,088	445,904	467,380	506,281

or, by using a tricolour filter, the adjoining images on the outer filter strip would overlap, and red and blue colours would appear more or less purple.

3. The narrower the individual screen lenses, the less the striped screen of the image will be visible on projection; on the other hand, the resolving power increases and enables even the smallest images to be resolved into their details. Naturally, the grains of the emulsion should be small compared with the width of the stripes of the filter image. In the Agfacolor process, in which the width of the lenticular elements is 0.028 mm., the images of the individual colour stripes have a maximum width of 0.009 mm., or twenty times the wavelength of blue light. With respect to resolving power, the lenticular screen is superior to the mosaic colour screen. Owing to the geometrical co-ordination of the object, lens, screen, and image, details even smaller than the width of the lenses are reproduced in their correct position as regards colour. With images smaller than one-third the width of the screen, mixed colour details cannot be resolved into their individual colour elements.

4. The quality of the picture depends largely on the photographic qualities of the emulsion, particularly on its colour sensitivity. The latter, in turn, determines

COLOUR CINEMATOGRAPHY

the choice of the filter colours with respect to their spectral transmission. The judgment and decision on this matter and the choice of the filter combination must be based merely on principles of subjective psychology and on average taste.

Theoretically lenticular films can be printed, but not by the ordinary contact method—numerous possibilities of doing this have been described and patented. It is important to preserve the original co-ordination between the density and the lens elements. The geometrical co-ordination between the silver grain, the lens elements, and the projection lens must be identical in both the copy and the original.

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Subtractive Processes

What skilful limner e'er would choose
To paint the rainbow's varying hues,
Unless to mortal it were given
To dip his brush in dyes of heaven?

SCOTT.

Projection Normal; Camera may be Normal or Otherwise

A. TWO-COLOUR SUBTRACTIVE PROCESSES

General Principles.—In subtractive processes the film is itself coloured, each picture being a complete colour photograph. It may be a two-colour print of limited colour range, or it may be a three-colour print providing differentiation in chromaticity adequate to reproduce with remarkable accuracy the colours of the natural world. Until very recently all subtractive colour films were two-colour. Subsequent to the early productions of Hernandez-Mejia in 1913, a considerable number of processes appeared. Reference will be found to some of these in the Historical Summary in this book. Early two-colour Technicolor aroused criticism from the public of the definition; and the peculiar variety of colour harmony, which was the outcome of the particular pair of roughly complementary colours chosen, was never really popular. The "reds" had an unpleasant salmon-pink tone, and the "blues" were of a very green hue. But defects of this kind are inseparable from two-colour, because one is always effecting a compromise and engaging in stratagems in the endeavour to rob Peter to pay Paul! It is possible with careful choice of two dyes, or mixtures of dyes, or of certain inorganic compounds, to get fairly true flesh colours and a very pleasing general effect which in many respects is not unlike the restricted palette of some of the eighteenth-century painters; but the total absence of genuine blues, violets, purples, pinks, lavenders, and, above all, yellows and yellow-greens, severely limits the potentialities of a two-colour process. The recently introduced Technichrome, which is printed in two colours, is an improvement on the original two-colour Technicolor, but it inevitably suffers from defective colour rendition and the definition leaves much to be desired. Nevertheless, the colour is attractive within its range.

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The late Dr. Troland of Technicolor said, in discussing the limitations of two-colour:

In some two-colour pictures which have appeared in the past, the selection of primary colours was ill-advised, causing even the flesh tints, which are the most important colours, to be rendered very poorly. If the flesh tints are properly reproduced, other colours can take care of themselves.

The fact that two-colour negatives are easily obtained by means of bipack exposed in a normal camera has lengthened the survival of the better two-colour processes. Examples are Cinecolor and Trucolor. Some further discussion of bipack negative will be found in Chapter VI.

Bipack negatives are generally printed for two-colour subtractive work on double-coated positive film. An Eastman film stock suitable for this purpose is *Duplitized Positive*, Type 1,509. This is a yellow-dyed emulsion coated on both sides of standard film base. A similar product is made by Du Pont and Gevaert. Technichrome is printed by imbibition on single-coated film base.

As typical of two-colour processes involving inorganic colour toning, the following formulæ represent reliable data (by courtesy of Dufay-Chromex Ltd.):

Film-Stock Gevaert Double-Coated Positive (viz., coated on both sides of the film base)
Developer D/16

TWO-COLOUR TONING OPERATION

Timetable

Operation.	Minutes.	Totals.
1. Preliminary Wash and Wipe	4	4
2. Blue Toning (one side)	2½	6½
3. Wash	8	14½
4. Clearing Bath	1	15½
5. Uranium Toning (other side)	5	20½
6. Wash	5	25½
7. Fixation	1	26½
8. Wash	8	34½
9. Ammonia Bath	1	35½
10. Wash	1	36½

FORMULÆ

Green-Blue Toner (Cyan)

A	{ Ammonium Persulphate	50 gm.
	{ Ferric Alum	125 "
	{ Water	2,000 c.c.
B	{ Oxalic Acid (Cryst.)	150 gm.
	{ Water	2,000 c.c.

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C	{ Pot. Ferricyanide	100 gm.
	{ Water	2,000 c.c.
D	{ Ammonium Alum	200 gm.
	{ Water	2,000 c.c.

For use take: 1 part A
2 parts B
1 part C
2½ parts D

Dilute with equal quantity of water. Add hydrochloric 10 c.c. for 500 c.c. of bath.
Toner applied by twelve felt-covered rollers (or by the flotation method).

Clearing Bath—to increase Transparency of Uranium Toning.

Hydrochloric Acid (conc.)	..	..	..	260 c.c.
Pot. Oxalate	..	..	..	96 gm.
Water	..	..	..	8,000 c.c.

Uranium Toner (Red-Orange)—Total Immersion.

Pot. Oxalate	..	..	..	96 gm.
Uranium Nitrate	..	..	..	84 "
Hydrochloric Acid (conc.)	256 c.c.
Pot. Ferricyanide	72 gm.
Water	8,000 c.c.

Fixing Bath.

Hypo	20 per cent.
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Ammonia Rinse—to modify Hue of Green-Blue.

Ammonia 880	8 c.c.
Water	8,000 "

The unexpected revival of interest in two-colour processes has brought Cinecolor into the foreground as a major competitor to Technicolor, and today there is an output from the Cinecolor laboratories of no less than one hundred and twenty million feet of print per annum. This extraordinary turn of events in the history of the colour film is to be explained partly as an economic phenomenon, and partly as an answer to the insistent demand for a product possessing acceptable quality but which, for its production, does not necessitate a beam-splitter camera and the rather meticulous limitations imposed by the more complex three-colour competitors.

In fact, a two-colour process can, in the nature of things, only provide a minute proportion of the total range of colour sensations, and the undoubted satisfaction which has apparently been registered by audiences confirms the belief held by many colour film experts that the average film-goer is far less sensitive to the subtleties of colour than had been generally supposed. It does not seem that two-colour films have impressed even film technicians as being markedly inferior, or indeed different in any way, from films possessing a full colour gamut, and whilst producers can hardly be blamed for exploiting the advantages

which this situation presents, it is difficult for the technicians not to feel some regret at the re-emergence of a type of process the limitations of which marked an earlier phase of the evolution of the colour film.

From these remarks it must not be concluded that Cinecolor, for example, is not of its class admirable, but it may be safely predicted that it would either have to be so modified as to become a three-colour process or suffer a decline in popularity the moment there is offered a three-colour product of comparable cost and ease of manipulation. And this prediction can be made because, while it may not be obvious to audiences, producers and directors are perfectly well aware of the grave limitations imposed upon them by the two-colour process, forced as they are to select subject matter and to devise treatments which will conceal the fundamental weaknesses of the two-colour range of chromaticities.

It is to be noted that the ease of handling two-colour film has attracted the attention of news-film producers and an attempt is to be made to introduce regular issues made in the United States. Furthermore, not to be outdone, the Technicolor organization has recently announced its intention to make available their product in a two-colour form under the new trade name of "Technichrome." This is certainly a case of history conforming to the cyclic law, since we return again, perhaps in a slightly modified form, to the pre-Cucaracha days of The Wax Museum and The Black Pirate.

With regard to the frequently advanced objection to double-coated positive as not being capable of being projected with perfect definition, R. H. Cricks has observed, "Mathematics disproves this idea. The thickness of the film base is .005 in.; assuming a 5-in. projection lens, this means a difference in image plane of $1\frac{1}{1000}$ th the focal length. At a throw of 100 feet this means a difference in focus of only just over an inch; quite normal angles of rake produce a difference of two or three feet, which passes unnoticed."

If colour prints made from bipack negatives suffer from lack of definition, this is to be ascribed solely to scattering of the light rays in passing through the first emulsion to reach the back element of the bipack, for which reason every technical device must be adopted to ensure the maximum contact between the two films.

References

- CRICKS, R. H., "Two Colours are Better than None—as Conditions are," *Kine Weekly*, London (July 10, 1947). British Studio Section Supp., p. XXIX.
- CRESPIAL, W. T., "History of Bi-pack Photography," *Internat. Phot.* (Dec. 1946), p. 5.
- BOYLE, J. W., and BERG, B., "Studio Production with Two-color Bipack Motion Picture Film," *Journ. Soc. Mot. Pict. Eng.*, 48 (Feb. 1947), pp. 111-116.
- HOLM, W. R., and KAYLOR, J. W., "1,000-Foot Bipack Magazine and Adapter," *Journ. Soc. Mot. Pict. Eng.*, 53 (July 1949), 58.

EXAMPLES

Cinecolor (Product of Cinecolor Corporation, Burbank, California)

Classification.—American two-colour subtractive process. (Three-colour prints have also been processed.)

Camera.—Normal, equipped with special Cinecolor bipack convex roller pressure plate and suitable double magazine. An N.C. Mitchell is usually employed.

Negative Film Stock.—Eastman Bipack. Type 1236 Ortho and Type 1235 Pan. For daylight Type 1234 Ortho is substituted.

Printing.—Eastman Type 5509 "Duplitized," coated on front and rear of film support.

There is no reliable information, but one side is doubtless toned Prussian Blue (ferroferricyanide) and the other side is dye-toned by use of an iodide mordant. (Traube.) (B.P. 506,450.) Cinecolor patents cite the following iodine bleach mordant. A "Predip" of potassium iodide 7 to 14%, and generally 10%; the bleach being iodine of 0.02% to 0.6% plus potassium iodide of 1-4%. The method of application is most likely to be by flotation. All printing, optical or contact, is necessarily carried out on step-by-step registering pilot-pin printers. The sound track is iron-toned silver, and hence blue.¹

Remarks.—Cinecolor is the direct descendent of W. Van D. Kelley's "Prizma," from which a large family of "processes" stemmed, amongst others "Kedacolor," "Kelleycolor," "Magnacolor," "Multicolor," etc. W. T. Crespinel has stated that he was associated with Kelley and in 1928 was interested in Multicolor. Crespinel claims to have been instrumental in developing a practicable bipack with the assistance of Du Pont. He recalls that they called the earliest bipack "Rainbow Negative." Du Pont subsequently sold this material as "Dupack." The first major feature was M.G.M.'s "Gallant Bess," photographed by John Boyle. It is claimed that today Cinecolor is processing a hundred million feet of print per annum. Cinecolor is also processing both 16-mm. and 8-mm. prints. Reduction negatives are made from the original 35-mm. bipack negatives.

Reference

KEANE, N., *Amer. Cinematographer*, 29, 373, 389-91.

Cinecolor 16 mm. Technique

Summary of Method.—Essentially the normal pair of two-colour 35-mm. separation negatives are so orientated and registered that they may be used for printing face to face a double-coated positive stock sandwiched between, but for this special purpose each 35-mm. negative bears two parallel 16-mm. separation negative image strips, the blue-

¹ It has recently been revealed that the cyan image is also dye-toned, the iodide mordant being employed, as for the red-orange toning. The sound-track is now a normal silver image lacquer-protected during the toning operations.

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green printer negative bearing also two parallel sound-track 16-mm. negatives correctly aligned in relation to their associated 16-mm. negatives. Thus using the 35-mm. laboratory equipment two 16-mm. prints are yielded from *one* run of a 35-mm. negative strip of film.

Description.—Production of 16-mm. Cinecolor began in 1939. A. M. Gundelfinger and J. Smith of Cinecolor claim to have been the first to devise the method of printing two 16-mm. strips side by side on one 35-mm. strip, which could be processed on their existing machines. They christened this method "double-sixteen." The pair of release 16-mm. positive are slit from the 35-mm. strip *after* processing. Double-sixteen negatives or positives necessitated the provision of alternative sprockets and pulleys on the processing machines with a simple mechanical change-over control (Fig. 186).

The Cinecolor optical printer, which is the pivot of this technique, is capable of several types of operation (Fig. 187).

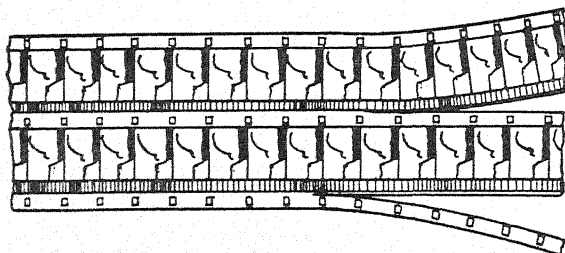


FIG. 186A.—Cinecolor double-sixteen arrangement for printing, perforation, and slitting.

1. Printing optical reduction 16-mm. negatives on 35-mm. stock from master 35-mm. duplicate positive intermediates.
2. 1 to 1 projection printing of 16-mm. Viz.: 16-mm. separation negatives from 16-mm. Kodachrome original positives.
3. Enlarged 35-mm. separation negatives from 16-mm. Kodachrome.

Projection can be from either end of the optical printer. The projector lamp is 1,000 watt, Biplane filament.

Each pair of parallel 16-mm. negative images must be placed on the 35-mm. strip with the utmost precision, since a complementary pair has to be printed on a second 35-mm. strip for register printing face to face with the first strip with "duplitized" positive sandwiched between. Finally, two negative sound tracks have to be printed in the correct position relative to their associated 16-mm. image strips. These sound-track negatives are confined to the cyan-printer negative.

Cinecolor perforate all their negative and positive stock. They use three rows of standard 16-mm. perforations, one in the middle and one along each edge, employing a special perforator.

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The developing machine provides the following facilities:

1. Developing time variable from 3 to 35 minutes.
2. Tension on film never exceeds three-quarters of a pound.
3. Turbulation and circulation of developing and fixing solutions.
4. Micro-variable drive compensated for film stretch in wet and dry stages, without increasing tension.

Printer light intensities are resistance steps brought into circuit by relays actuated pneumatically, or electrically, by means of punched strips of 35-mm. film stock. Nine resistance positions provide 21 printing lights. An auxiliary resistance adds 19 additional printer steps. The two sound tracks are printed simultaneously. "The images of the two sound tracks are turned optically to permit the sound negative and positive stock to be driven directly from the same shaft."¹

When slitting takes place a 3-mm. strip is removed which contained one set of perforations.

Previous to copying Kodachrome 16-mm. originals they are hardened by the Peerless process for surface hardening. A black-and-white reversal 16-mm. print is first made for editing purposes. Clear leader with instructions written on it is cut into the Kodachrome at points where lap dissolves or other special effects are to be inserted. It is claimed that both two and three colour separations are made. Separation negatives are developed to the low gamma of 0.35, but this may vary for the individual colour-record negatives.

PATENTS HELD BY CINECOLOR CORPORATION—10/11/46

<i>United States.</i>	<i>United States.</i>	<i>United States.</i>	<i>British.</i>
1,744,459	1,922,725	2,141,354	E.P. 447,412
1,595,295	1,928,325	2,183,661	" 466,290
1,562,319	1,927,886	2,218,001	" 473,993
1,784,515	1,992,989	2,226,339	" 506,450
1,686,907	1,998,154	2,272,556	" 522,984
1,734,476	2,005,254	2,272,557	" 525,549
1,897,368	2,001,322	2,281,075	" 532,870
1,897,369	2,008,904	2,295,107	" 535,812
1,893,698	2,009,689		" 538,555
1,927,887	2,016,666		" 538,556

(Other patents pending.)

Chemicolor. (Obsolete.)

The German Ufacolor process as worked in England (1930).

Camera.—Normal. Bipack (Agfa).

Printing.—Chemical toning of double-coated film. Probably iron and uranium toning with possible addition of dyes and mordanting.

Colorfilm Process. (Probably Obsolete.)

An American two-colour subtractive process (U.S.P. 1,633,652).

Camera.—Probably bipack in a standard camera equipped for bipack.

¹ Tess, S. N., *Photo Technique* (Nov. 1941), p. 17.

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Printing.—Double-coated film was used. The film was first printed on both sides, using the appropriate two-colour negatives, and then developed in the usual way. Both sides were then toned red-orange with uranium. All treatments so far were done by immersion. The side that was to be toned blue-green was then passed over wicks that fed a solution of iron and acid to one side of the film, converting the red-orange tone to blue-green.

Colorcraft. (Probably Obsolete.)

American two-colour subtractive process. Worked in 1929.

Camera.—Beam-splitter or alternatively bipack.

Printing.—Single-coated film was used. The images were dye-toned by the iodide mordanting process. No details available. Probably based on the Traube patent (D.R.P. 187,289, 1905).

Coloratura Process. (Probably Obsolete.)

An American process which belonged to the Pathé Exchange, Bound Brook, New Jersey. Two-colour subtractive.

Camera.—Negatives were made with normal bipack in a standard bipack camera—probably a Mitchell with the four-roller pressure-pad in the gate.

Printing.—Printing was carried out on double-coated positive stock, and this was dye-toned on one side and metallic-toned on the other. The double-coated film, having been printed on both sides with the respective two-colour negatives in registration, was first given a special treatment on one side to make it dye selective, and from then on the film was totally submerged to receive both colours, the blue-green tone on one side and the red-orange dye on the other side, neither colour going to the wrong side. The film was treated in a continuous processing machine.

Fox Color. (See Early Kodachrome.)

Dascolour. (Probably Obsolete.)

Subtractive two-colour process.

The patents of M. L. J. Dassonville of Brussels describe the unusual system of chemical and dye toning which was used for this process. The technical development was sponsored by M. André Debrie, the French cinematographic engineer and manufacturer.

Camera.—Debrie bipack special model. Normal cameras may be used if they are adapted to expose bipack.

Printing.—E.P. 377,411 described a method by which successive exposures were made upon the *same* side of a normal positive film. After the first exposure the film was developed and fixed as usual. The film was then resensitized by an iron salt which bleached the silver

image and rendered it capable of being mordanted. The second image was printed and processed in colour, after which the first image was dyed *through* the second. Thus after printing, say, the first red-orange negative, and developing and fixing, the film was resensitized with a solution of ferric chloride containing oxalic acid, dried, and exposed under the blue-green negative. After blue-toning with potassium ferri-cyanide, the film was washed and immersed in a mordant bath of potassium iodide, and was then passed through a bath of orange-red dye and washed with acidulated water. The second image might be printed from a positive and developed with potassium ferrocyanide. The process, it was claimed, could be made into one of three colours by adding the third component by mechanical printing, by which was meant, presumably, imbibition printing. Instead of ferric chloride, the oxalate, tartrate, or citrate might be used.

E.P. 379,558: The process in this specification was modified for the production of a combined sound and picture film by printing the sound record on the film *after* the resensitizing step. During the first exposure the sound track was masked and the unexposed silver removed when the first image was fixed. After the film had been resensitized, the sound record was printed simultaneously with the second colour record, the two being recorded on the same negative.

Remarks.—It was stated that this procedure had been considerably modified, but the details of the process have not been published. Debrie designed a special printer capable of printing both negatives simultaneously on to one frame. How this assisted, if the process followed the method described in the patents, is not clear.

Fullcolor

(Product of the Trimble Laboratories, Inc., Hollywood, California.)

Two-colour (three-colour also claimed) subtractive process.

Camera.—Normal. Bipack, employing standard accessories; or 16-mm. standard equipment.

Negative Film Stock.—Eastman bi-pack, it is presumed, or 35-mm. separation negatives optically enlarged from 16-mm. Kodachrome originals. Two of the three-strip negatives of a beam-splitter Technicolor record have also been employed.¹

Printing.—Duplitzed Eastman Type 5509 is used. Toned one side to Prussian Blue. Other side dye-toned. The flotation method is said to be employed for surface application of the toning solutions.

Harmonicolor. (Probably Obsolete.)

A two-colour subtractive process based upon the work of M. Maurice Combes, a French chemist. Complete equipment existed in France for processing film.

¹ Viz., the bipack pair of Eastman three-strip material.

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The first showing of an Harmonicolor film was at the Curzon Cinema, London, March 23, 1936. The film was "Talking Hands," directed by Ivor Campbell and produced at the Walton-on-Thames Studios.

Camera.—Agfa bipack was used. Any camera suitably equipped with bipack gate and magazines might be used. Normal two-colour filters.

Printing.—The negatives were printed on double-coated positive by means of a Debie double-coated positive contact printing machine (see Fig. 185). The film was developed, fixed, and washed. It was then surface stained with mixtures of basic dyes. A mixture of rhodamine and auramine was used for the red-orange side of the film and a mixture of malachite green and any suitable violet or blue-violet for the blue-green side. The inventor claimed that the lighter densities would be toned yellowish, whereas the more dense silver areas would be orange or red. Similarly, on the other side of the film the lighter tones would be greenish and the deeper tones bluish or violet. Exactly the same dichroic phenomenon was discovered by A. Hamburger (see p. 258). The next stage of the process also closely follows Hamburger's Polychromide formulæ, since the film was then immersed in a mordanting bath consisting of chromic acid, potassium ferrocyanide, and sulphuric acid, after which the film was cleared in potassium metabisulphite and finally washed.

The staining of the film prior to immersion in a chromic acid mordanting bath was not original, as this was first practised by Hamburger.

Remarks.—The dye mixture proportions might be altered, depending upon the nature of the subject-matter. The whites were clean and the colour range adequate. The sound track was printed on the blue-green side and was blue in the finished film.

Patents were applied for in most countries, but it is difficult to see wherein the process differed in any important respect from that patented in E.P. 203,358, 1922, by Hamburger.

Harriscolor. (Probably Obsolete.)

American two-colour subtractive process operated in 1930. This company purchased the Kelley Color Co. in 1928.

Camera.—Two alternative methods were used: (1) A beam-splitter camera of substantially similar design to the Technicolor camera, *i.e.* the usual half-silvered prism and two gates at 90° to each other. In descriptions of the prism it is stated that the silvering was in fine lines "or circles." (2) An original but impracticable system is described in which two Bell & Howell cameras were mounted on a single base at right angles to each other. A reflector of some sort was placed in such a position that light was reflected from the object at 90° to one of the cameras, while the light which passed through the reflector was

recorded by the camera directly behind the mirror. Possibly a prism block was employed.

Printing.—Normal single-coated positive emulsion was used. The negative recording the red-orange was printed through the base of the positive film, and this film was then developed, washed, and toned with an iron solution and again washed and dried *in the dark*. Upon the residual emulsion which was on the surface a print was made from the blue-green negative record. This was developed in a solution which did not destroy the blue-toned image beneath; the film was then fixed and washed, and finally the top image was toned red-orange by a bath which did not affect the ferric image (presumably by uranium). The base was slightly yellow, in an attempt to get a species of three-colour effect.

Remarks.—A method similar to the above double-toning is that in which the first image is toned blue with a ferric toner and before fixing a second image is printed in the remaining silver halide. During development the alkali present in the developer converts the blue image to a colourless salt. The second image is then treated with a vanadium mordant bleach and dye-toned. When the film is passed through an acid solution the original ferric blue image is restored.

Kelleycolor Process.

The late William van Doren Kelley was responsible for the "Prizma" process. Negatives were exposed at a speed of 32 pictures per second in a normal camera equipped with a rotating filter carrying the usual two-colour taking filters. Prints were made on double-coated film, the alternate frames being selected by a skipping contact printer. One side of the film was toned blue-green by an iron solution, and the opposite side was toned red-orange with uranium.

According to another description, the "Prizma" process was as follows:

The first image is toned blue-green with an iron toner and, before fixing, a second image is printed in the remaining silver halide. During development the alkali present in the developer converts the blue image to a colourless salt. The second image is then treated with a vanadium mordant bleach and dye-toned. When the film is passed through an acid solution the original blue-green image is restored.

The "Prizma" patents were apparently taken over by Consolidated Film Industries and marketed under the trade name of "Magna-color."

In E.P. 228,887, 1923, a process is claimed in which two images are formed in the same layer; one image is printed first, developed, and toned, the layer then being cleared in a bath containing ammonium bromide and potassium dichromate, and the second image then printed on the unexposed silver salt, developed, and toned. As an example, the

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first image is printed on the layer through the transparent support from a red-orange record, developed for three minutes in amidol, and toned blue-green in a bath of vanadium oxalate, ferric ammonium oxalate, oxalic acid, and potassium ferrocyanide. The layer is then bleached with ammonium dichromate and bromide. After washing and drying, the second image is printed on the front of the layer from a blue-green record negative, developed for three minutes with amidol, fixed in hypo, toned red-orange in uranium nitrate, potassium oxalate, hydrochloric acid and ferrocyanide, and finally fixed.

Kelley seems to have been the first to patent registering pins for a printer, but the practice had been common for many years. He described the now universally adopted method of causing a full-fitting pin to pass through one of the perforations of the two films on one side only so that shrinkage was taken up on one side only of the full-fitting pin. A second pin fitted the opposite perforation from top to bottom but not from side to side (E.P. 193,363).

Kelley was a prolific patentee. A few of his patents are here given:

E.P. 129,638	
E.P. 130,603	.. Printer for double-coated stock, and registration means.
E.P. 160,137	.. Dye-toning.
E.P. 228,887	
E.P. 333,931	.. Film double-coated on one side only, and means for producing two-colour image in same.
E.P. 402,113	.. Alternate frames only of positive are dyed. The film is projected at twice normal speed.
U.S.P. 1,133,730	
U.S.P. 1,250,023	
U.S.P. 1,250,024	
U.S.P. 1,259,411	.. Double-coated stock.
U.S.P. 1,278,161	.. Dye-toning.
U.S.P. 1,278,162	.. Double-coated stock.
U.S.P. 1,322,794	.. Screen process.
U.S.P. 1,337,775	.. Screen process.
U.S.P. 1,411,968	
U.S.P. 1,431,309	.. Kelley and Dunning screen process.
U.S.P. 1,505,787	.. Imbibition printing and a grey key.

Kodachrome. (The Earlier Process.)

(Eastman Kodak Company.)

The name "Kodachrome" was originally used for a two-colour subtractive process worked out by J. G. Capstaff of the Kodak Research Laboratories. This process should not be confused, therefore, with the contemporary Kodachrome film.

Camera.—Beam-splitter. Both images were recorded on a single film.

Printing.—The printing had to be carried out with positives. The first stage was, therefore, to make a set of intermediate master positives. These were made by contact printing from the original negative. A projection printer embodying an elaborate prism mirror system

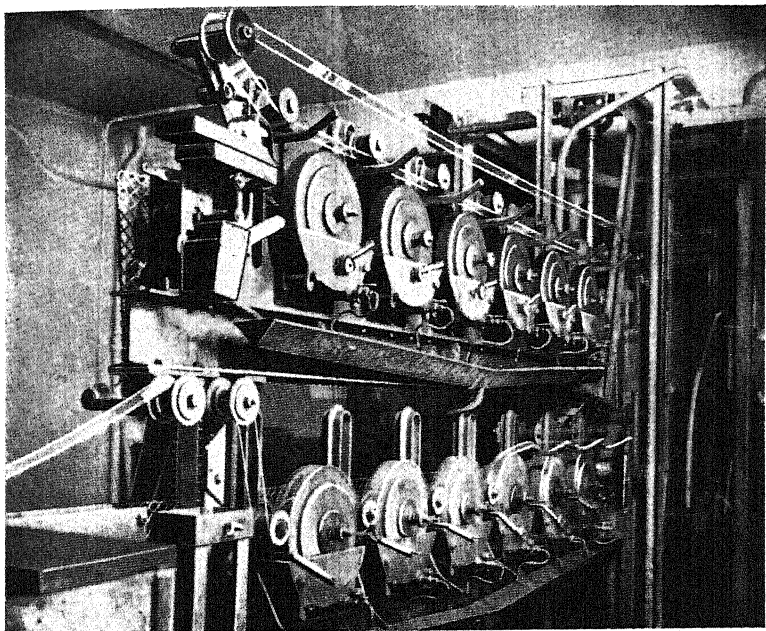


FIG. 184.—Polychromide dye-coating machine.

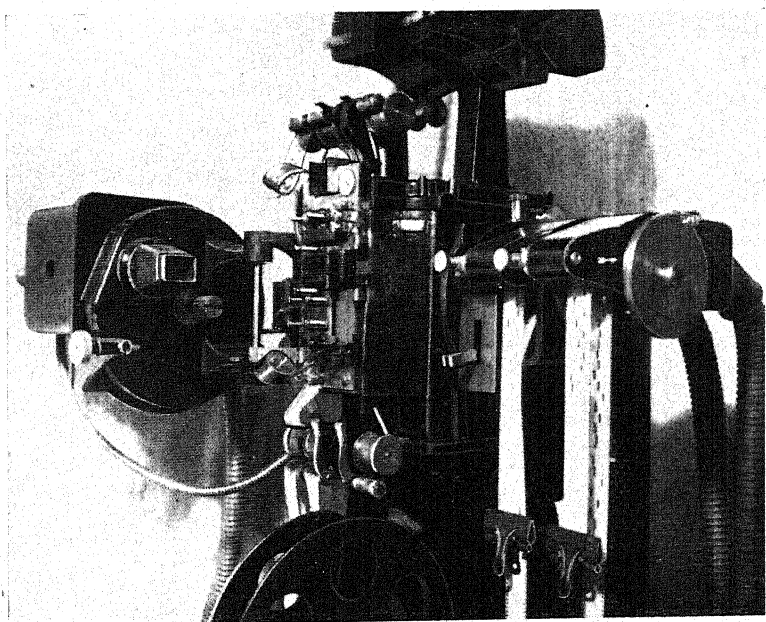


FIG. 185.—Debie printing machine for printing both sides of double-coated positive simultaneously.

(Facing p. 336)

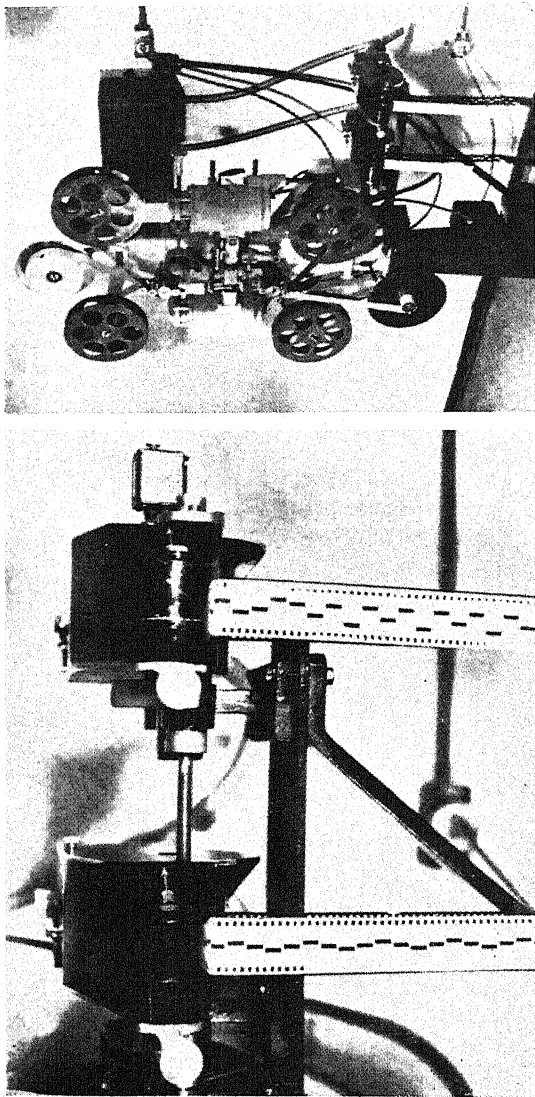


FIG. 186.—Printer for double-sixteen colour prints: Cinecolor.

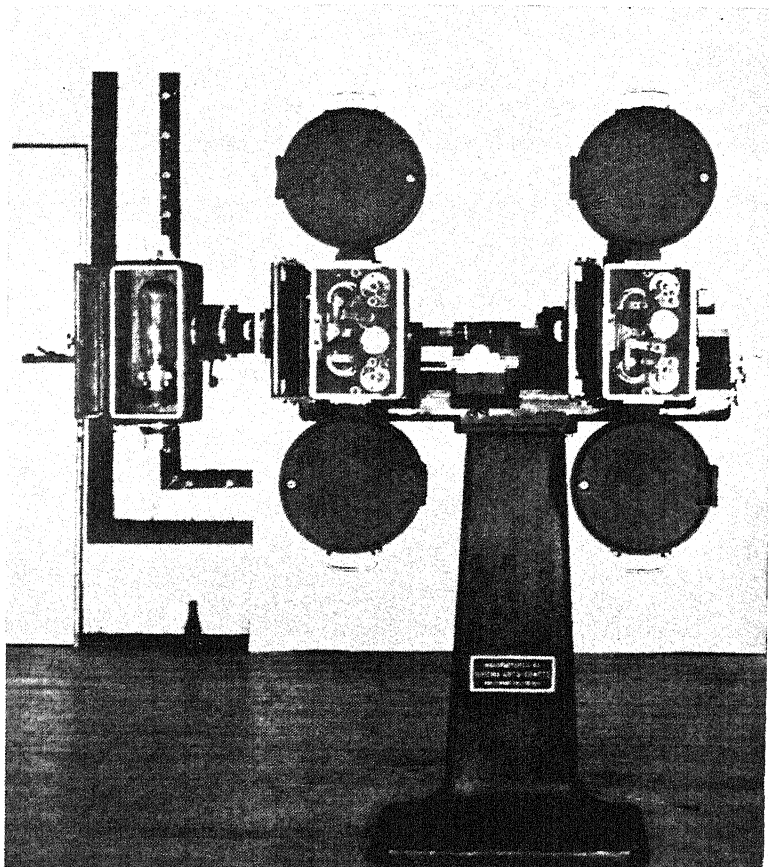


Fig. 187.—Cinecolor Optical Bench Copying Printer.

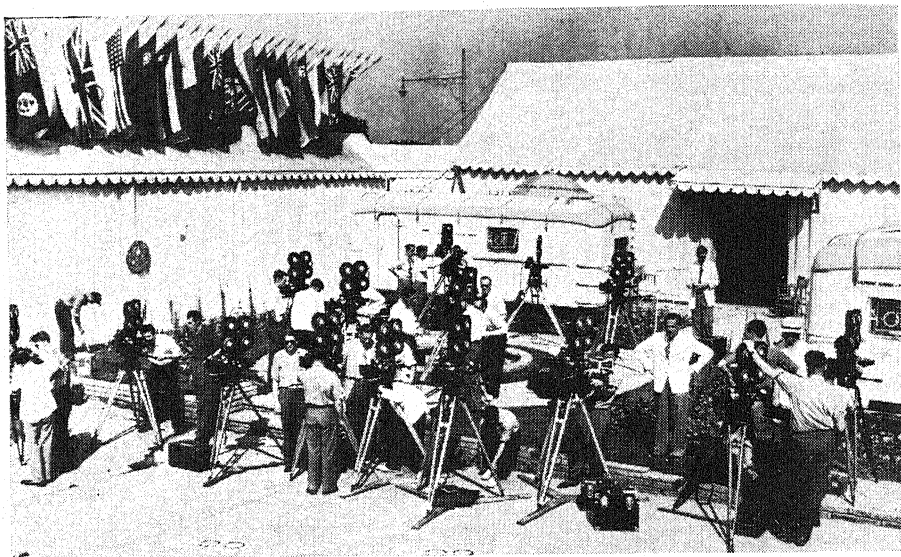


FIG. 190.—Rehearsal the day before the Olympic Games opened, 1948. Seventy-five cameramen worked under the producer Castleton Knight on the film "XIVth Olympiad—The Glory of Sport." The Newall bipack cameras are shown in preparation for their work with "Technichrome."

(By courtesy of the J. Arthur Rank Organization Ltd.)

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enabled both sides of double-coated film to be simultaneously printed from the single master positive bearing the pairs of complementary images.

The double-coated film now bearing *negative images* was developed and bleached; the bleach bath hardened the film only in the parts where the image had been printed. The two sides of the film were then dyed in the usual subtractive complementaries, the dye being absorbed by the gelatine only in the unhardened areas, thus providing positive dye images.

The Kodachrome bleach was:

A.	Potassium ferricyanide	..	..	..	37.5 gm.
	„ bromide	..	..	..	56.25 „
	„ dichromate	..	..	..	37.5 „
	Acetic acid	..	..	..	10 c.c.
	Water	..	..	..	1,000 „
B.	Potassium alum, 5 per cent. solution.				

A and B were mixed in equal proportions.

The films were fixed after bleaching. The drying was important and had to be as even as possible. Humidity of the film had also considerable bearing on the results; the drier the film the cleaner the highlights and the greater the contrast.

J. G. Capstaff patented the making of positives of different gammas by varying the development time. See also Comstock (Technicolor) and Brewster (U.S.P. 1,469,811).

PATENTS

E.P. 13,429 (1915)

U.S.P. 1,196,080

Magnacolor.

(Consolidated Film Industries, U.S.A.)

An American two-colour subtractive process still worked by the Consolidated Film Industries division of Republic Pictures Corporation. This concern was licensed by the owners of the "Prizma" patents, which it will be remembered was the name under which the patents of William van Doren Kelley were commercialized. Herbert J. Yates now operates the "Trucolor" process, which will presumably supplant Magnacolor.

Camera.—Normal bipack is used in a standard camera equipped with special gate and magazines according to usual bipack practice.

Printing.—Double-coated positive film is used. One side of the film is toned blue by an iron solution, and the opposite side is toned red-orange by mordanting with an iodide and dye-toned by the familiar technique of flotation. Under the Mason patent each side is treated, without danger of the solutions toning more than one side at a time, by floating the film on the surface of the solutions.

Multicolor Process

American two-colour subtractive process. Operating in 1931.

Camera.—Bipack ("Dupack" was used) exposed in a Mitchell

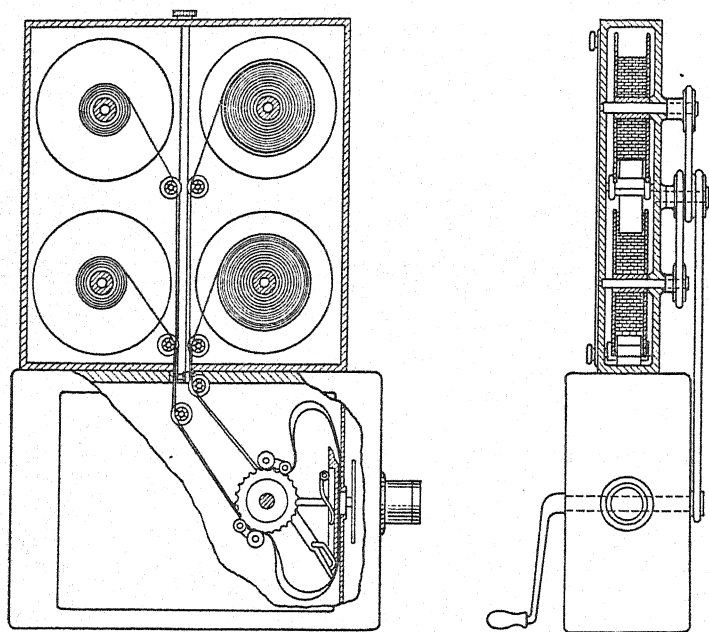


FIG. 188.—Multicolor E.P. 340,238.

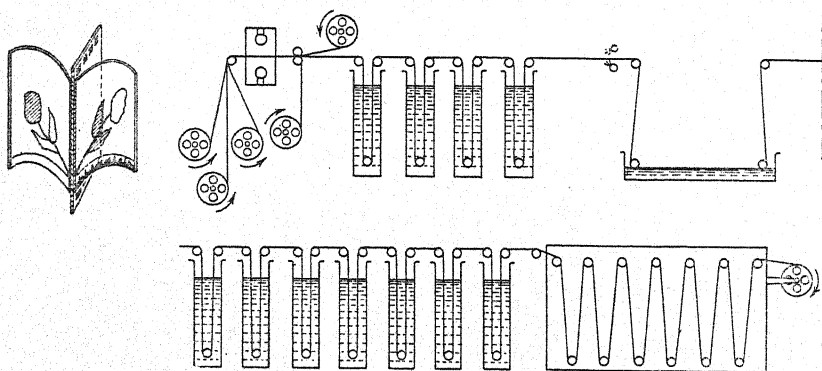


FIG. 189.—Multicolor E.P. 360,819.

camera fitted with a special pressure plate with four rollers. A shim was placed in front of the ground glass to make the plane of the ground glass coincide with the plane of the emulsions of the bipack (Fig. 188). A

Bell & Howell camera could also be used, the pins on the back pressure plate being increased to eleven in number to ensure contact, and 0.006 in. was removed from the aperture plate to make the emulsions come in the same plane as when using one film normally. A No. 86 Wratten filter was used for daylight exposures, but this was omitted for tungsten lighting.

Printing.—The two negatives were both printed from simultaneously in a contact printer of the type in which two light-sources on either side of a gate enable both sides of double-coated film to be printed at the same time. This type of printer was first used by A. Hamburger for the Polychromide process, Debie having constructed the printer (see above, Fig. 185).

The first operation is to apply a ferric toner to one side of the film. Neglecting washes, the film is then immersed in a solution which tones the image on the other side red-orange, leaving the blue image unaffected. This uranium toner serves also as a mordant for a dye which next follows, and which adds brilliance to the red-orange image. The film is then passed through hypo, washed, dried, and varnished. The sound track is printed on the iron-toned side and is therefore blue.¹ (Fig. 189.)

MULTICOLOR PATENTS

E.P. 339,323, 1929
E.P. 339,971
E.P. 340,238, 1929
E.P. 360,819, 1930
E.P. 376,514, 1931
E.P. 384,334, 1931

Photocolor Process. (Probably Obsolete.)

(Photocolor Corporation.)

American two-colour subtractive system. Operating in 1930.

Camera.—Beam-splitter taking two images. Prism system of beam-division.

Printing.—Double-coated positive film was printed with an optical printer, both images being printed simultaneously on either side of the film. The print was then dyed by contact blue-green on one side and red-orange on the other. No further description has been divulged. Probably iron and uranium were employed, as in most of these two-colour American processes then worked.

Note.—From the above vague description it is to be supposed that the procedure was substantially the same as in Polychromide. The writer has not been able to trace any patent for the camera.

Polychromide Process. (Obsolete.)

This process was developed in England by an American chemist, the late Aron Hamburger, whose name was originally brought into promi-

¹ Otis, Russell M., "The Multicolor Process," *Journ. Soc. Mot. Pic. Eng.*, 18, No. 1 (1931), p. 5.

nence by his portrait colour photography, for which he had established a studio in London before the first world war. He had taken out certain patents for still-colour cameras and toning processes (E.P. 28,722, 1912, A. E. Conradi and A. Hamburger; and E.P. 20,880, 1911). The former patent describes means for applying distortion to a reflector by the application of pressure on different points around the edges, in order to correct for the unequal distortion produced in the transmitted image when a plain reflector is used. The latter patent was for toning a print yellow by means of mercuric chloride and potassium iodide, of which formula Hamburger always claimed to be the originator. Later, in 1918, appears a patent (E.P. 136,595, 1918, A. Hamburger and W. E. L. Day) in which is described a beam-splitter camera for motion pictures with two gates at right angles to each other and a reflector similar to that described in Specification 28,722, 1912. In E.P. 203,358, 1922, is described the method of dye-toning which ultimately became known as the "Polychromide" process. He describes the method of exposing an orthochromatic film sensitized with erythrosine and a panchromatic film sensitized with pinacyanol. These two films were exposed in the Hamburger beam-splitter camera. Positive prints are made from these on the opposite sides of double-coated positive film. A mixture of magenta and auramine is then applied to the positive printed from the orthochromatic film, and a mixture of malachite green and helio safranin to the positive printed from the panchromatic film. The positive film is then bleached in a solution containing chromic acid and potassium ferrocyanide, afterwards cleared in potassium metabisulphite, and then washed and dried. Hamburger claimed that the positive from film 1 (the orthochromatic film) exhibited a gradation from red to yellow, whereas the positive printed from film 2 (the panchromatic) had all tones from green to blue, the whole, therefore, giving the effect of a four-colour process! The bleached silver image furthermore provided a grey key. However, this effect was due probably far more to the fact that the clearing action of the metabisulphite is quicker for the magenta than for the yellow, which resulted in the lighter tones tending to become yellow-orange, while the deeper tones remained red (Figs. 184 and 185).

With minor modifications the process was still being worked in London in 1933 exactly as above described. Negatives were generally obtained with Agfa or Du Pont bipack, instead of using the beam-splitter camera, a Debie bipack camera being employed.

The most interesting contribution to the technique of dye-mordanting processes made by Hamburger lay in the order of his procedure. He was probably the first to dye the film *first* and to bleach and mordant *afterwards*. This method seems to have resulted in a considerable gain in evenness, as mordanting processes are notoriously liable to yield continuously variable colour, than which there is no more disagreeable fault in colour films.

SUBTRACTIVE PROCESSES

POLYCHROMIDE FORMULÆ

Positive Developer.

Metol	7 gm.
Sodium Sulphite (anhyd.)	25 "
" Carbonate	125 "
Pot. Bromide	1.7 "
Water	1,000 c.c.
Dilute 1-7	

Mordanting.

Pot. Iodide	17.5 gm.
" Ferricyanide	2.5 "
Chromic Acid	0.5 "
Pot. Dichromate	1.25 "
Water to	250 c.c.
Time: 7 minutes	

Bleach (or Discharge Bath).

Pot. Metabisulphite	5 per cent. solution
Time: 25 minutes	

DYE-TONING

Red-Orange

A {	Magenta or Fuchsin	2 gm.
	Spirit	15 c.c.
	Water (212° F.) to	100 "
B {	Auramine O	2 gm.
	Spirit	100 c.c.

For use take: 100 parts A
 25 " B
 10 " Glycerine

Blue-Green.

A {	Malachite Green	40 gm.
	Industrial Alcohol	225 c.c.
	Water	1,000 "
B {	Helio Safranin (Holliday)	40 gm.
	Industrial Alcohol	200 c.c.
	Water (212° F.)	1,000 "

For use take: 100 parts A
 32 " B
 3 " Acetic Acid
 6 " Glycerine

POLYCHROMIDE PATENTS

E.P. 123,786	E.P. 203,358
E.P. 123,787	E.P. 237,941
E.P. 136,595	E.P. 261,054

COLOUR CINEMATOGRAPHY

Sennett Color. (Obsolete.)

(Sennett Laboratories.)

An American two-colour subtractive process operated in 1930.

Camera.—Bipack in a normal camera equipped with special gate and magazines.

Printing.—Double-coated film was used. One side was toned blue with an iron toner, and the other side was toned red-orange with uranium. (Processing probably similar to Multicolor.)

Sirius Kleuren Film Maatschappij. (Obsolete.)

(Utrecht, Holland.)

A two-colour subtractive process.

Camera.—E.P. 316,141, 1929, described a beam-splitter having two gates at right angles to each other, the beam being diverted by a single transparent reflector between the lens and the film. The film was shown in the drawing as travelling across both gates. Such an arrangement would require a pull-down of two or more frames.

Printing.—E.P. 283,548, 1927, proposed the use of a single layer of opaque screening in double-coated film. The opaque layer was to be placed between the emulsion and the celluloid on one side of the film only. Such a layer was to be coloured with manganese peroxide or by a dyestuff soluble in the developing and fixing baths.

E.P. 341,477 dealt with a machine for applying dye or liquid to opposite sides of a double-coated film. The machine was very similar to Hamburger's Polychromide dye-applying apparatus.

The Sirius process was, as far as the writer is aware, a dye-mordanting process, but no details appear to have been published. It has been stated that a prism beam-splitter was used in connection with the process.

Remarks.—Most of the Sirius patents were assignments from L. Horst, a German photographic inventor.

Reference

Licht Bild Buhne, 22 (Aug. 17, 1924), p. 14.

Spectracolor. (Obsolete.)

This was a two-colour subtractive process corresponding to the German Ufa process marketed for a time in England under the above trade name.

Camera.—Agfa bipack was exposed in a Vinten camera equipped with special bipack gate and magazine.

Printing.—Double-coated positive film was dye-toned blue-green on one side and red-orange on the other by a mordanting process, the details of which have not been published.

Remarks.—The prints were clean, having excellent definition and gradation. There was also complete freedom from variation, a disagreeable fault so often present in dye-mordanting processes. The printing was of equal technical excellence to the earlier Technicolor two-colour process.

Technichrome

(Technicolor Limited, London, England.)

Two-colour Technicolor process.

Camera.—Normal, fitted for Bipack. Special magazine available in England by Newall to accommodate 400 feet of bipack. The two strips come off spools on one side of the magazine and are fed into the camera separately. Just above the gate, they come together, with a special roller device to eliminate the air cushion between them so that good registration of the two frames is obtained in the gate. Focus is adjusted one five-thousandth of an inch further back than normal so that the image is focused on a plane corresponding to the middle of the two strips. Film stock used is presumably Eastman Bipack Types 1234 or 1236, and 1235.

Printing by Imbibition.—As for Technicolor three-colour. See Technicolor.

Remarks.—The re-introduction of two-colour printing by the Technicolor organization is historically remarkable. Such a retrogressive step can only have been brought about by lack of an adequate supply of prism three-strip cameras in England, or by temporary economic circumstances. The prints are made on the standard "I.B." pin-belt machine and it is understood that instead of using a typical red-orange and blue-green printing in two stages, three matrices are prepared from the two negatives, thus the red-orange represents the result of two printings by the standard magenta and yellow dyes. This method would permit matrices to be made of varying contrast. For example, a soft gradation yellow and a high-contrast magenta would yield a hue-shift towards orange-yellow and yellow in the highlights; thus making use of a dichroic effect. (See Polychromide.) This artifice noticeably extends the chromaticity range. The process was used on a large scale in the filming of the XIVth Olympiad, at Wembley, in 1948 (Fig. 190). The release prints were palpably inferior to standard Technicolor in colour and definition.

Trucolor

(Operated by Consolidated Film Industries, a division of Republic Pictures Corporation, 1740 Broadway, New York City, N.Y., U.S.A.)

American two-colour (or three-colour) subtractive process.

Camera.—Normal. N. C. Mitchell equipped with special pressure plate and bipack magazine.

Negative Film Stock.—Eastman Bipack. Type 1234 Ortho for daylight, Type 1236 for tungsten illumination at 3,200° to 3,400° K., combined in either case with Type 1235 Pan.

Printing.—Special two-layer Eastman coating, the respective emulsion layers incorporating probably resin-protected, or in any case non-diffusing, colour couplers. Neither of the two layers is specially sensitized, as has been the practice with monopack materials in the past, but are separated by a gelatine filter layer preventing "cross-printing." (E.P. Application No. 34,262, Nov. 1946.) The under layer of a material of this type must necessarily be printed through the film support. The printer embodies two film printing gates each associated with its independent source of light, relay rack, control strip and stop-motion unit for the matte boxes. After leaving the first gate, the rawstock takes a half twist and thence passes through the second gate where an image is exposed on the opposite surface of the film (viz., through the film support). The light sources are tungsten filament lamps. The processing machine is a top drive unit with one sprocket per shaft. Two developing tanks, a hypo tank and wash tank are located in the dark room section; while bleach, wash, hypo and final wash tanks—together with the track treatment unit—are in the white light. The whole process is completed in some 65 minutes. It is stated that Trucolor prints are on safety film base without any reason being advanced for this. The base is presumably Eastman aceto-butyrate film. Both sides of the print are finally coated with Eastman protective lacquer.

Remarks.—Consolidated Film Industries Inc. operates the largest motion picture processing laboratory in the world at Fort Lee, New Jersey. This great plant is the creation of Herbert J. Yates, who also formed Republic Pictures Corporation, of which Consolidated Film Industries is now a division. Until recently the colour process sponsored by Mr. Yates was Magnacolor (see page 337) and for many years they encountered the worries which have ever haunted toning processes. The general manager at Fort Lee, Mr. Arthur J. Miller,¹ in 1940 conceived the idea of using non-colour-sensitized emulsion incorporating colour couplers as a substitute for dupli-tized film and the former toning process. The Eastman organization collaborated in the production of this type of positive film, in effect, a two-layer monopack.²

Clearly this process is of great interest. It bears a close resemblance to Dufaychrome which, while a three-colour process, can be worked equally well as a two-colour process. It is in the predicted three-colour Trucolor that we might have some reservations until proof is forthcoming. And this is because any middle layer of a triple-coated stock can only yield a perfectly steady colour balance provided that the

¹ Also a director of Republic Pictures Corporation.

² The incorporated colour couplers are of the type used in Ektachrome.

coating of the upper layer of emulsion, through which necessarily it must be printed, is so perfectly coated that only negligible differences of coating weight are present throughout the whole roll of film. This is excessively hard to achieve. The situation is similar to that which would exist if one tried to make a print through a neutral filter continuously varying in density. The effective density of the top emulsion coating could not be permitted to vary more than .02 in either direction. Such even coatings are excessively difficult to achieve, as the makers of Kodachrome, Ansco Color and Agfacolor discovered. Time will show. There is no reason why the cost of the two-colour two-layer film should be much in excess of "dupli-tized" film of the former type. The only extra cost is that of the colour components, which in any case are being made by Eastman in high volume. It will be interesting to watch the evolution of this process to the three-colour stage. This will involve the use of a prism beam-splitter or separation negatives derived from monopack, a procedure which has many points against it.

Republic has successfully made a number of feature films employing the Trucolor process for release prints, and large plans are announced for the near future.¹

Ufacolor. (Obsolete.)

German two-colour subtractive process.

Camera.—Normal. Agfa bipack was used.

Printing.—Double-coated film toned with ferric toner one side and probably uranium on the other. Dye-toning may have been included.

¹ Three-colour prints are now in production at Fort Lee, employing Du Pont release positive, Type 275 (see page 27). Negatives are of the successive frame, single strip type; the subject-matter being necessarily static—namely, cartoons.

SUMMARY OF TYPICAL SUBTRACTIVE PROCESSES—TWO-COLOUR

Camera.	Negative Record.	Positive Print.	Image Coloration Technique.	Sound-Track.	Example.	Patents.
Normal	Bipack	Single coating on one side of support. Normal positive	Print red-orange negative. Develop and fix. Re-sensitize with ferric chloride and oxalic acid. Print blue-green negative. Develop with pot. ferricyanide. Mordant with pot. iodide. Dye red-orange and wash with acidulated water	Blue-green (ferric ferricyanide)	Dascolour Belgian (obsolete)	E.P. 377,411 379,558
Beam-Splitter	Pan. and Ortho.	Single coating on one side of support. Normal positive	Print red-orange negative record <i>through the support</i> . Develop, wash, but omit fixation. Iron-tone stage follows in darkness. Print blue-green in contact with residual unexposed halide. Develop, fix and tone orange-red with uranium nitrate	Iron-toned blue	Harriscolor 1928-9 U.S.A. (obsolete)	
Normal with rotating red-orange and blue-green filter. Exposed 32 pictures per second	Pan. Single Film	Single coating on one side of support. Normal positive	Print red-orange negative record. Develop with amidol, wash but omit fixation. Iron-tone stage follows in darkness. Print red-orange and develop. During development the alkali present in the developer converts the ferric image into a colourless salt. Mordant and bleach with vanadium. Dye-tone. When the film is passed through an acid solution the original ferric image is restored.	Iron-toned blue	"Prizma" Kelley-color Process U.S.A. (obsolete)	E.P. 160,137 228,887 U.S. 1,278,161 1,411,968 etc.
Beam-Splitter and	Pan. and Ortho.		or			

SUBTRACTIVE PROCESSES

Normal	Bipack		Print red-orange negative record through support. Dev. 3 mins. with amidol. Iron-tone (without having fixed). Formula contains vanadium oxalate, ferric ammonium oxalate, oxalic acid and pot. ferricyanide. Bleach with ammonium dichromate and bromide. Wash and dry. On reformed halide print blue-green negative record. Develop with amidol. Tone with uranium nitrate, hydrochloric acid and ferricyanide. Fix and wash	Iron-toned blue	Colorfilm (1929) U.S.A.	U.S. 1,633,652
Normal	Bipack	Coated on front and rear of film support	<i>Both sides</i> toned red-orange with one side converted to blue-green with iron and acid by surface treatment	Iron-tone ? blue	Fullcolor U.S.A.	
Normal	Bipack, viz., Eastman type 1234, 1235, also 2-colour separation from Monopack Kodachrome 16-mm. Technicolor Pos.	Coated on front and rear of film support. Viz., Eastman type 1509 or 5509	Print, develop, fix and wash respective sides. Iron-tone one side by flotation. Other side dye-toned. (No data)			
Normal	Bipack. Viz., Eastman type 1234-1235 or 1236-1235	Single coating on one side of support. Normal positive picture image. PRINTED WITH MASTER POSITIVES (MATRICES) Sound printed normally	<i>Three successive dye transfers</i> are superposed by means of wash-off gelatine relief matrices. The magenta and yellow printers are made from the same negative providing red-orange component. Blue-green component less green than normal in two-colour processes	Silver	Technichrome	See Section on Technicolor

COLOUR CINEMATOGRAPHY

Camera.	Negative Record.	Positive Print.	Image Coloration Technique.	Sound-Track.	Example.	Patents.
Normal or Beam-Splitter	Bipack. Viz., Eastman types 1234-1235 or 1236-1235 Pan. and Ortho.	Coated on front and rear of film support. Eastman Duplified Filmstock Type 1509 Safety Film Base	Print, develop, fix and wash respective sides. Iron-tone one side by flotation. Other side iodide mordanted and dyed with basic dyes such as Fuchsin plus Auramine O. Alternatively mordant and dye red-orange first and iron-tone other side subsequently. Alternatively, the cyan component may be dye-toned by mordanting	Iron-tone blue or silver. Track reserved by lacquer	Cinecolor U.S.A.	E.P. 447,412 466,290 473,993 506,450 522,984 525,549 532,870 535,812 538,555 538,556
Beam-Splitter (2 images on 1 film)	Single Pan Film	Made from master positives. Coated on front and rear of film support. Printing by projection	Develop without fixing and bleach in pot. ferricyanide; pot. bromide; pot. dichromate and acetic acid. Fix, wash and dry. Dye respective sides red-orange and blue-green. Dye is absorbed by <i>unhardened</i> areas	Never used	Kodachrome (the earlier process) (obsolete)	E.P. 13,429,1915 U.S. 1,196,080
Normal	Bipack	Coated on front and rear of film support	Print and develop, fix and wash respective sides. Iron-tone one side by surface application. <i>Immerse</i> in uranium toner. This serves as mordant for dye application to red-orange uranium increasing saturation and altering hue. Fix, wash and <i>varnish</i>	Iron-tone blue	Multicolor (obsolete)	E.P. 339,323 340,238 360,819 376,514 384,334
Beam-Splitter or	Pan. and Ortho. or	Coated on front and rear of film support	Print, develop, fix and wash respective sides and apply spirit solution of following dyes: For red-orange—Magenta and Auramine	Silver. Track reserved with cellulose nitrate	Poly-chrome (obsolete)	E.P. 203,358

SUBTRACTIVE PROCESSES

Normal		For blue-green.—Malachite Green and Heflo Safranin Bleach and mordant with chromic acid and pot. ferricyanide. Clear in metabisulphite. Wash			
Normal or Beam-Splitter	Bipack. Eastman Type 1234 and 1235 or 1236 and 1235 1 Pan. 1 Ortho.	Two layers of emulsion non-sensitized coated on one side of film support. Emulsions contain non-diffusing colour coupling dyes. Safety Film Base	Colour coupling developer. Viz: Diethyl <i>p</i> -phenylene diamine sulphate	Silver (precise method unpublished. Possibly redeveloped after formation of silver sulphide or reserved with lacquer	Trucolor U.S.A. E.P. 626,979
Normal	Bipack	Coated on front and rear of film support with non-sensitized emulsions containing non-diffusing colour coupling dyes to give red-orange and blue-green	Print respective sides by contact. Developed with colour coupling developer. Viz., Diethyl <i>p</i> -phenylene diamine sulphate	As above	Trucolor U.S.A.

B. THREE-COLOUR SUBTRACTIVE PROCESSES

Introduction.—Since with two subtractors the range is very restricted, historically it became essential to perfect three-colour processes. Many years passed before the problems of the three-colour subtractive process applied to motion picture film were solved. The Technicolor process of imbibition printing was well adapted to the requirements, since there was no inherent difficulty in adding a further printing stage to the perfected two-colour technique. Hence Technicolor was the first subtractive process to achieve full three-colour, and having led the way they have held the lead ever since. The Technicolor camera was designed for making two-colour separation negatives; it was adapted to three-colour by the expedient of using bipack in one of the two gates. It is not an ideal one-shot camera, but marvellous results have been achieved nevertheless. The late Dr. Troland of Technicolor thought that the ultimate method would take the form of a tripack or, rather, monopack film, and was an early patentee. Technicolor for many years foretold the advent of a "monopack" camera material. By 1942 a few pictures were being photographed on Kodachrome 16-mm. reversal film. Enlarged separations were made from these 16-mm. colour positives, and such negatives were used to make the imbibition matrices. Early pictures in which sequences were photographed on monopack (Kodachrome) were "Dive Bomber" and "Captains of the Clouds."

In England the bleach-out Gasparcolor positive film had a short but promising life before the war put a stop to its manufacture by Gevaert in Belgium. More may yet be heard of this beautiful process, since it is known that Dr. Bela Gaspar is very active in his laboratories in Hollywood.

Before the recent war Kodachrome 16-mm. had achieved universal success in the substandard motion picture field, and, with Agfacolor, I.G. Farben had begun to offer an excellent alternative. During the war 35-mm. Kodachrome reversal was employed by U.S. services, while the Germans during 1942 perfected negative-positive Agfacolor, with which a considerable number of films were made. The Germans equipped a laboratory in Prague for processing. As soon as the U.S. and the British forces occupied the great Agfa I.G. Farben factory at Wolfen (near Berlin) they extracted all the relevant technical data, and this was subsequently transmitted to the allied photographic manufacturers. It is certain that within a short time a substantially identical monopack film will be made by several firms. Indeed, the Agfa type of monopack may become a standard product of all photographic manufacturers. Gevaert have already made large quantities of this type of film (viz., Gevacolor)

In the U.S. during the war, Ansco Inc., a branch of General Aniline and Film Corporation (originally controlled by I. G. Farben), intro-

duced Ansco Color Film, a reversal material based on the pre-war Agfa-color manufacturing formulæ. This was made available in 16-mm. and 35-mm. cartridges. After the U.S. entered the war the Government seized the great factory at Binghamton and considerable quantities of 35-mm. reversal colour film were produced for service purposes. At the same time experimental work was begun with the object of perfecting negative-positive 35-mm. film.¹ This material has not yet been released for use in the motion picture industry, but its debut is unlikely to be long delayed. The data seized in Germany will no doubt enable improved colour couplers to be embodied, and it should then be equal in performance to the latest German product. In 1946 three 35-mm. motion picture reversal stocks were released for professional use. Much will depend upon what is accomplished with these materials.

Ektachrome, Dufaychrome, Kodachrome, Ansco Color, and Agfa-color are all derived from the original conception of Fischer and Siegreist (E.P. 15,055/1912; U.S.P. 1,055,155), the fundamental difference between these processes and Kodachrome being that in the former the dye couplers are in the monopack and in the latter they are in the developer solutions. It is to be noted that Mannes and Godowsky also proposed the former process (in U.S.P. 1,954,452) and that their idea was preconceived twenty-five years earlier, even the coupler compounds being practically identical. It remained for the Eastman Kodak research workers to bring the original concept into actual being. Mannes and Godowsky were Fischer revivalists. We ought to attend the lesson they have taught us. How many more discarded discoveries may be lying in a literary coma for a quarter of a century awaiting only the magic wand of the research director to call them into glorious life! Undoubtedly, the outstanding problem in a monopack which embodies the couplers is to prevent them from diffusing or wandering to adjacent layers. It is in the means to achieve this substantivity that efforts have been in the main directed, and success was obtained by the I.G. chemists by adding to the coupler extremely complex hydrocarbon residues such as an 18-carbon chain stearyl, thus providing a very large molecule which can move only very slightly, if at all, in the gelatine lattice.

Judkins and Varden of Ansco have listed the following as desirable characteristics of colour formers. This list gives some idea of the tremendous task which faced the organic chemists who brought this process to a workable stage:

- "1. The colour formers (couplers) must not diffuse from one emulsion layer to another.
2. The compounds must be water or alkaline soluble prior to their introduction in the light-sensitive emulsions, but non-diffusing from the gelatine layer in water or alkaline solution thereafter.

¹ A masked negative roll-film, sold under the name "Plenacolor," is now on the American market.

COLOUR CINEMATOGRAPHY

3. The dyes which the colour formers eventually produce must have the proper absorption characteristics for subtractive synthesis.
4. Each of the colour formers must be capable of forming an appropriate dye by conjugation with the oxidation products of a single colour developing agent.
5. The colour formers must be transparent, colourless, and incapable of causing light scatter within the emulsion layers.
6. The compounds must be stable before and after film development.
7. The dyes formed during film development must have satisfactory dark stability and a white light stability comparable to other dyes commercially acceptable.
8. The colour formers must exert no desensitizing or sensitizing action on the silver halide emulsions in which they are incorporated.
9. Each colour former must react readily with the oxidation products of a suitably chosen developing agent to give comparable dye yields, but must not react with the oxidation products of the negative developer in the reversal process.
10. The colour formers must be commercially producible in large quantities on a commercial basis."

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Note: B.I.O.S.=British Intelligence Objectives Sub-Committee.
C.I.O.S.=Combined Intelligence Objectives Sub-Committee.
F.I.A.T.=Field Information Agency, Technical (U.S.A.).

COLOUR DEVELOPMENT AND MULTILAYER PATENTS

(I.G. Farbenindustrie Akt. Ges.)

E.P. 375,338	E.P. 457,326	E.P. 486,043	E.P. 500,945
E.P. 376,795	E.P. 458,400	E.P. 486,424	E.P. 501,190
E.P. 379,423	E.P. 459,027	E.P. 486,495	E.P. 502,665
E.P. 379,934	E.P. 460,580	E.P. 486,496	E.P. 503,077
E.P. 383,486	E.P. 460,653	E.P. 486,517	E.P. 503,318
E.P. 383,799	E.P. 461,006	E.P. 486,848	E.P. 503,832
E.P. 387,197	E.P. 461,559	E.P. 487,769	E.P. 504,376
E.P. 387,519	E.P. 464,398	E.P. 488,048	E.P. 505,027
E.P. 389,341	E.P. 465,823	E.P. 488,548	E.P. 505,214
E.P. 390,327	E.P. 467,087	E.P. 488,555	E.P. 506,514
E.P. 396,585	E.P. 468,848	E.P. 488,853	E.P. 507,009
E.P. 396,646	E.P. 468,946	E.P. 489,093	E.P. 508,011
E.P. 399,387	E.P. 471,520	E.P. 489,161	E.P. 508,468
E.P. 400,951	E.P. 472,224	E.P. 489,162	E.P. 511,039
E.P. 402,521	E.P. 475,191	E.P. 489,164	E.P. 511,790
E.P. 404,856	E.P. 476,672	E.P. 489,274	E.P. 512,060
E.P. 410,481	E.P. 479,752	E.P. 489,845	E.P. 513,234
E.P. 418,157	E.P. 479,838	E.P. 489,853	E.P. 513,554
E.P. 427,887	E.P. 480,778	E.P. 490,516	E.P. 516,584
E.P. 431,072	E.P. 481,274	E.P. 490,517	E.P. 516,606
E.P. 432,969	E.P. 481,275	E.P. 490,844	E.P. 516,937
E.P. 436,587	E.P. 481,501	E.P. 491,958	
E.P. 442,160	E.P. 482,652	E.P. 491,959	
E.P. 444,198	E.P. 483,000	E.P. 492,518	
E.P. 446,977	E.P. 483,271	E.P. 492,523	
E.P. 451,347	E.P. 483,548	E.P. 492,648	
E.P. 454,088	E.P. 484,698	E.P. 493,308	
E.P. 454,788	E.P. 485,861	E.P. 493,869	
E.P. 454,842	E.P. 485,862	E.P. 494,144	
E.P. 455,556	E.P. 486,005	E.P. 499,131	

EXAMPLES

Agfacolor

(Manufactured at Wolfen, Germany, by I.G. Farbenindustrie Akt. Ges. The factory is now in the Russian Zone of occupation.)

Classification.—Three-colour subtractive process. Integral tripack, or monopak, with non-diffusing colour couplers incorporated in three emulsion layers.

Camera.—Normal.

Projection.—Normal.

Printing.—Normal, with suitable grading for colour.

Processing.—Colour development with colour coupling compounds.

COLOUR CINEMATOGRAPHY

AGFACOLOR ORIGINS

Tripack.

DUCOS DU HAURON
1897 "La Triplice Photographique,"
Paris.
"The day when commerce will
provide the three kinds of emulsion
coated on films—called by du
Hauron 'Polyfolium Chromo-
dialytique.'"

U.S.P. 544,666.
F.P. 216,465—1895.

J. H. SMITH, 1903.
First integral tripack.

U.S.P. 781,469.
B.P. 19,940—1904, etc.

Colour Development.

B. HOMOLKA—1907.
F.P. 457,079—1913. Indoxyl and thio-indoxyl.
Discoverer of first true colour developers.

RUDOLF FISCHER—1909.
D.R.P. 253,335/257,160—1911.
U.S.P. 1,055,155.
E.P. 15,055—1912.
D.R.P. 257,167—1911.
Coined the terms, "colour development" and
"colour formers."
U.S.P. 1,079,756—1913.
U.S.P. 1,102,028—1914.
Addition of substances to developers to form
coloured precipitates in the presence of oxidized
silver bromide.

WILHELM SCHNEIDER—1932.
D.R.P. 579,078—1932.
First work on "substantivity" of anti-halation dyes.
F.P. 803,566—1936—Substantive groups.
F.P. 827,626—1937—Stearines, etc.
F.P. 828,502—1936—Sensitizing and layer arrange-
ments.
F.P. 849,299—1938—Ditto.
F.P. 833,153—1937—Spectral overlap of negative
material.

Printing Light and Spectral Sensitivity.
F.P. 818,057—1936.
F.P. 836,530—1938.
F.P. 874,457—1940.
F.P. 879,095—1941.

Colloidal Silver Filter Layer.
F.P. 816,296—1936.
S.P. 224,670—1940 (Sound-track).

Spray Wash.
I.P. 384,379.

Viscous Bleach.
I.P. 379,198—1938.

Masking.
D.R.P. 743,535—1939.

Printing.
F.P. 818,057—1936.
F.P. 816,029—1936—Infra-red absorption.
F.P. 825,186—1936.
F.P. 879,035—1941.
F.P. 836,530—1937—Printing filters.
D.R.P. 695,109—1938—Grading Control.
I.P. 379,974—"Multiplier" tester.
I.P. 384,439—Selecting Box.

1936 Agfacolor Reversal Film introduced.
1939 Negative Film manufactured. 10/10 Din.
1940 Speed increased 4 times.

TYPES OF AGFACOLOR FILM

Width.	Type.	Meter Rating.	Illumination.
16 mm.	Reversible. Daylight Type. Acetate Base	Weston. 8-10 G.E. 12	Sunlight, 6,000° K.
16 mm.	Reversible. Tungsten Type	12 16	Tungsten, 3,200° K.
16 mm.	Duplicating. Reversible	— —	—

Width.	Type.	Meter Rating.	Purpose.
35 mm.	Negative. Type B. Daylight Type. Nitrate Base	Weston. 8 G.E. 12	Camera Record
35 mm.	Negative. Type G. Tungsten Type. Nitrate Base	12 16	„ „
35 mm.	Positive, Release. Acetate Base	— —	Release Printing

General Description.—The origins of this process stem from the discoveries of B. Homolka (1907) and Rudolf Fischer (1911). The former discovered that certain intermediates, such as those that gave indigoid dyes, can develop exposed silver bromide producing simultaneously an insoluble dye. Such agents are indoxyl, 3-hydroxy-thio-naphthene, etc. This has been called *PRIMARY COLOUR DEVELOPMENT*.

There is another way, namely that of using the development process indirectly to form dyes. Fischer discovered that dyes, such as those belonging to the quinimine and azomethine class, can be formed when exposed silver bromide is developed with *p*-phenylene diamine together with coupling substances. During development *p*-phenylene, or its derivatives, reacts with phenols or naphthols or substances containing a reactive methylene group through the medium of oxidized silver bromide, to form strongly coloured insoluble dyestuffs, the developed silver image being at the same time produced. Fischer thus conceived the idea of mixing a developing agent, such as an aromatic diamine, or amino phenol and a *coupler* which could be a phenol or a body containing a negative methylene group. This has been called *SECONDARY COLOUR DEVELOPMENT*.

The next step was to incorporate the coupler in the silver halide layer or layers instead of adding it to the developer, but owing to the apparent impossibility at that time of making the dye-forming substances non-diffusing, Fischer, in 1911, had to abandon his project for making a multilayer colour film by applying these discoveries. The physical structure of a gel is such that the conditions for molecular diffusion are ideal. Hence our ability, amongst other things, to develop a gelatine emulsion. As gelatine can only trap coarse-grained particles insoluble in water, the dyes produced by colour development must be insoluble in water and large in structure. Next, the substances to be incorporated must not adversely affect the sensitivity of the silver halide emulsion. It does not seem strange that Fischer's idea was considered impracticable by emulsion experts.

The next important name is that of Dr. William Schneider of the Agfa organization (I.G.). He tells us that in 1934 instructions were issued that a colour process must forthwith be perfected. In 1936 Schneider and G. Wilmanns reported (*Agfa-Veroeffentlichungen*, Vol. V, p. 29) that a satisfactory solution of the problem had been completed.

Colour couplers similar to those discovered by Fischer were used but these were made fast to diffusion by attaching a *long-chain alkyl group*, since diffusion depends upon the physical dimensions of the particles determined by molecular weight and constitution. In general, a chain-like structure containing twelve carbon atoms is usually adequate. By virtue of these couplers containing a group soluble in alkali, it was feasible to incorporate them in the gelatine emulsion in an alkaline solution.

The developing agent in the Agfacolor process used to-day, is:

N-diethyl-p-phenylenediamine sulphate.

An enormous range of colour couplers is now known. As examples we give three typical:

With the above developing agent:

The coupler 1-phenyl-3-methyl-5-pyrazolone gives a *magenta* dye.
 „ „ acetoacetanilide gives a *yellow* dye.
 „ „ 1-hydroxy 2-naphthoic acid gives a *cyan* dye.

In 1936 Agfacolor Reversal film was made available in 8 mm. and 16 mm., the processing being carried out solely by the manufacturer. These films were of both daylight and tungsten types, the speed being roughly the same as that of Kodachrome.

Immediately following the occupation of Germany, investigation by the Anglo-American Service experts of the Agfa film factory at Wolfen, Germany, revealed that the Germans had developed to a commercial stage the long-promised 35-mm. negative-positive Agfa-

color film.¹ It is said that UFA were ordered by Goebbels to proceed with the production of feature-length pictures employing the Agfacolor negative-positive process, but they did not consider the method sufficiently perfected for feature productions and proceeded only because of the government directive.

One feature picture, "Die Frau meiner Träume," was brought to the U.S. and viewed by various producers, members of the Society of Motion Picture Engineers, manufacturers, and other groups concerned in colour film development, and was considered of sufficiently good quality to warrant a thorough investigation of the process in all its aspects. The picture "Baron Münchhausen" was in the opinion of the experts "of good quality as far as grain, sharpness and tone were concerned, and the colour generally pleasing. None of the colours were particularly saturated, the reds being quite dull. It was not as good as Technicolor."

It does not appear that any new developing machines or printers were constructed for the processing of the film, but modifications were made in existing equipment. Between 1940 and 1945 thirteen feature pictures were made (see list below) and some fifty shorts consisting of one or two reels. The material is particularly suitable for newsreel production, and a picture was made of actual combat in Russia. Lt.-Colonel R. H. Ranger (U.S. Signal Corps) and his associates considered that "the screen quality was inferior to the established American standard (presumably Technicolor); the results varied, but certain prints of one or two of the pictures were quite satisfactory in colour quality, and particularly impressive because of the sharpness of the screened picture. The latter was quite noticeable on medium-long and long shots. The method is capable of good results if proper control and equipment were used, but under the wartime conditions in Germany there was an apparent lack of good equipment and a generally laxity in quality control, resulting in many inferior prints being released."

Darrel Catling, A.R.P.S., one of the more intelligent of the younger British directors, had the following reaction to his first sight of Agfacolor: "In 'Immense' there was—with the exception of only one reel—a pretty fair balance maintained between one reel and another, though a mistiness was noticeable throughout most of the film. In 'Münchhausen,' although the balance between reels was much less good, it nevertheless mattered little; it was a phantasy on the one hand, and on the other the art direction, costume design, and colour planning were so brilliant, tasteful, and imaginative that deficiencies in the colour system were

¹ Squadron Leader G. C. Brock, who visited the Agfa film factory in June 1946, stated in the report (C.I.O.S. Trip No. 313) that "Agfacolor would seem to offer at least the possibility of a less grainy image than Kodacolor, and I was certainly impressed, in the screened pictures which I saw, with the high resolving power compared to Technicolor."

COLOUR CINEMATOGRAPHY

AGFACOLOR FEATURE RELEASES FROM 1940 TO 1945

<i>Picture.</i>	<i>Director.</i>	<i>Cameraman.</i>	<i>Studio.</i>
1. "Frauen sind doch bessere Diplomaten"	Jacobi	Tschet	UFA-Babelsberg
2. "Die goldene Stadt" ..	Harlan	Mondi	Prague Films and UFA-Babelsberg
3. "Baron Münchhausen" ..	von Baky	Krien	UFA-Babelsberg
4. "Das Bad auf der Tenne"	von Collander	von Baray	Tobis-Johannisthal
5. "Opfergang" ..	Harlan	Mondi	UFA-Babelsberg
6. "Immense" ..			
7. "Die grosse Freiheit" ..	Käutner	Krien	Prague Films and UFA-Babelsberg
8. "Kolberg" ..	Harlan	Mondi	UFA-Babelsberg
9. "Die Frau meiner Träume"	Jacobi	Tschet	
10. "Die Fledermaus" ..	von Bolvary	Winterstein	Wien Films "
11. "Figaro, oder Ein toller Tag"	Liebeneiner	Hoffman	
12. "Wir beide liebten Katharina"	Rabenalt	Krien	Prague Films and UFA-Babelsberg
13. "Das kleine Hofkonzert"	Verhoeven	Wagener	Tobis-Johannisthal

forgiven or forgotten. Moreover, a complete change of locale—coinciding with the change of the reels—often helped to cover up the lack of balance. Some thought, too, was given to the colour planning to avoid, as much as possible, revealing the system's weaknesses—though the revelation of one of its (at present) greatest faults was practically unavoidable: the inability to render a firm black. A fade is a wishy-washy 'grey-out' or 'brown-out'—so bad, in fact, that it is held only for the shortest time. Incidentally, some of the trick work was of a very high order. The short 'East Prussia on the Sea' was very uneven; much of it being little different from sepia-tinted monochrome, and pretty dense at that. But despite the eulogies which Agfacolor at its best brings forth, it appears, however, to have one limitation which many of its supporters overlook: in the case of the final Technicolor print there is merely one positive emulsion and three intermingled dye images on the celluloid base, whereas in the final Agfacolor print we have three negative emulsions (which have to be carefully balanced as to speed, colour, and thickness) with filter and/or isolating layers in between. Therefore, for the moment at least, it seems apparent that the Agfacolor system is unable to yield cheap prints for commercial release purposes; the cost cannot fail to be very much higher than that of a print consisting of one ordinary emulsion and three different dyes."

Post-war efforts have been confined to the Russians, who have made a number of news films of events such as Dr. Benes' triumphal return (followed so soon by tragedy) to Prague, and of a huge sports parade in Moscow. Both these films were publicly exhibited in the British

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theatres, and the writer heard innumerable people express very strongly their view that the colour was to be preferred to that of Technicolor. The expert saw that there was anomalous colour rendering due to the very defective magenta coupler, but here and there shots turned up of quite exquisitely satisfying colour, and it is perfectly certain that the Germans were at the beginning of a most important development. The men who were responsible for the achievement have since been interrogated, the opinion unanimously expressed being that they were forced into production before they had completed their task, and that great improvements would shortly have been made in the saturation of the couplers and particularly in the design of the coating machinery.

Figures are given in the FIAT Final Report No. 721 which do not support Catling's views about the high cost of Agfacolor. In the following table, cost figures per foot of 35-mm. Agfacolor negative and positive film are compared with those for black-and-white film. Dollar values are computed at \$0.235 to 1 mark, which was assumed to be the average before the war.

	<i>Negative.</i>				<i>Positive.</i>			
	<i>Agfacolor.</i>		<i>B. & W.</i>		<i>Agfacolor.</i>		<i>B. & W.</i>	
	<i>Mk.</i>	<i>\$.</i>	<i>Mk.</i>	<i>\$.</i>	<i>Mk.</i>	<i>\$.</i>	<i>Mk.</i>	<i>\$.</i>
Manufacturing Cost ..	0.15	0.035	0.046	0.011	0.15	0.035	0.021	0.005
Selling Price	0.45	0.11	0.14	0.033	0.25	0.05	0.04	0.0095
Processing	0.30	0.07	—	—	0.09	0.021	—	—

Production cost of the feature film " Die grosse Freiheit " (8,000 to 9,000 ft). was 3,500,000 marks, or, say, £205,000.

Late in 1944 and early in 1945, monthly production of Agfacolor film at the Agfa film factory at Wolfen amounted to an average of:

650,000 ciné ft. of negative.

3,300,000 ciné ft. of positive.

It is claimed that under the Russians this has been boosted to more than 15,000,000 ft. per month, but this output is very likely to fall, because it is likely that the Russians will not be able to obtain adequate supplies of colour couplers and sensitizers which formerly came from the present British area of occupation, and it will be a long time before production of the essential intermediates can be resumed.

Towards the end of the war the UFA processing laboratories at Neu Babelsberg handled:

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200,000 ciné ft. of Agfacolor negative per month.
1,000,000 ciné ft. of Agfacolor positive per month.

The processing rate in 1946 at the UFA laboratories at Koperick (in Russian-occupied Berlin) was said to be:

130,000 ciné ft. of Agfacolor negative per month.
650,000 ciné ft. of Agfacolor positive per month.

Release prints were always made from the original negative and no duplicate negatives were made. Special effects were made by indirect and trick methods which were not very satisfactory. No masking was used.

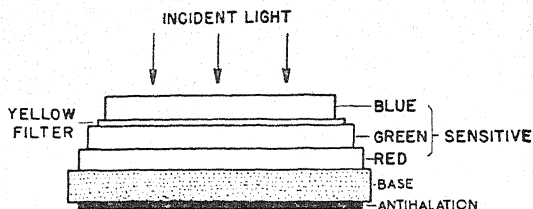


FIG. 191.—Agfacolor negative-positive film emulsion diagram.

Structure

All Agfacolor films have three emulsion layers and one filter layer (Fig. 191). The film base is first coated with a red sensitive emulsion. Directly on top of this is coated a green sensitive emulsion. Next comes a thin layer of colloidal silver which functions as a yellow filter. The final coating is an emulsion sensitive to blue only.

The yellow filter, needless to say, has the duty of absorbing blue light transmitted by the top layer, which would otherwise record in the green and red recording layers which are inherently blue sensitive (Fig. 192).

No non-stress surface gelatine coating is used and no gelatine coating divides the green and red recording emulsion. The colour couplers dispersed in these emulsions are chosen such that:

Yellow	is formed in the BLUE recording layer.	Top.
Magenta	„ „ „ „ GREEN „ „	Middle.
Cyan	„ „ „ „ RED „ „	Bottom.

The anti-halation coating is on the back of the film base in the negative-positive films and beneath the bottom layer of emulsion in the reversal film (see Table 57).

TABLE 57.—STRUCTURE—AGFACOLOR 35-MM. NEGATIVE AND POSITIVE

Layer.	Thickness.	Sensitizer.	Record.	Couplers.	Final Colour.
Top	6 microns	Normal silver bromide response	Blue	F 535 (Negative) F 535 } (Positive) Ta 521 }	Yellow
Yellow filter layer (colloidal silver)	2 microns	—	No record	—	—
Middle	6 microns	Rr 340 } 4 parts Rr 1,650 } 3 Rr 1,523 } 2 parts (Negative) Rv 340 } (Positive)	Green	Z 169 (Negative) (5%) or F 542 } combined Kö 302 } (Positive)	Magenta
Bottom	6 microns	Ma 1088 (Negative) Rr 1953 (Positive)	Red	F 654 (Negative) (5%) F 546 (Positive)	Cyan
Film base*	130-140 microns	—	—	—	—
Antihalation back coating, green dyed synthetic resin (Schultz-940).	2-3 microns Density 0.16 to 1.0 to red light	—	—	—	—

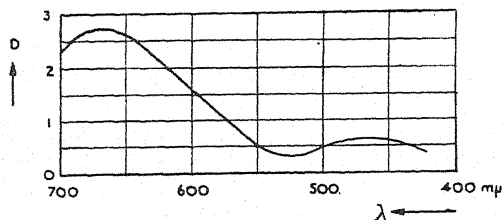
* Nitrate base for negative, cellulose acetate base for positive.

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Layer Thickness

The total thickness of the multiple layers does not exceed that of normal film, therefore the separate coatings are required to be extremely thin.

Red recording layer	..	6 microns (Bottom)
Yellow filter layer	..	1 micron
Green recording layer	..	6 microns (Middle)
Blue recording layer	..	6 microns (Top)



YELLOW FILTER ABSORPTION CURVE.

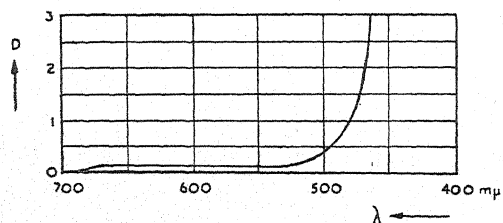


FIG. 192.—Absorption curve of antihalation layer of Agfacolor positive film.

Film Base

Nitrate base is used for negative. Thickness 130-140 microns (5/1000").

Acetate base is used for positive. Thickness 130-140 microns.

Spectral Sensitivity

Negative: Overlapping curves.

Red recording layer,	maximum	650 mμ.
Green " "	"	550 mμ.
Blue " "	normal	response.

This type of sensitizing is typical of most monopacks, such as Kodachrome, Kodacolor, Ektachrome, and Ansco Color film. The ideal sensitivities can be mathematically calculated relative to either practical

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or theoretical synthesis, by additive or subtractive methods, but the best compromise has to be effected with the materials available (Fig. 193).

Positive: Narrow band sensitizing, sharp cut in the green and red regions (Fig. 194).

Red recording layer, maximum 690 m μ .
 Green " " " 550 m μ .
 Blue " " normal response.

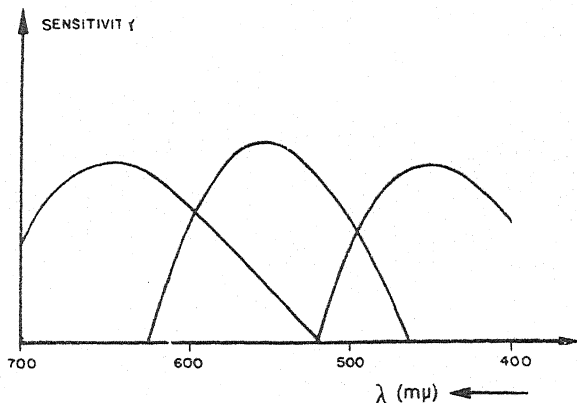


FIG. 193.—Sensitivity of Agfacolor negative film schematically.

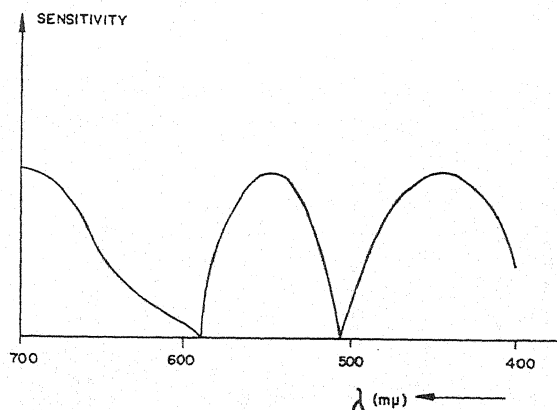
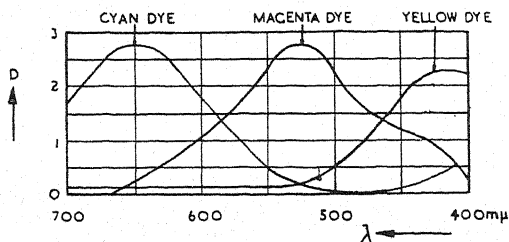


FIG. 194.—Sensitivity of Agfacolor positive film schematically.

Since it is desirable that the positive material should record in *each* of its respective layers light modulated by only *one* layer of the negative, the sensitizing should be designed to correspond to the maximum absorption and minimum overlap of the spectral transmission of the negative dyes (Fig. 195). The relation between negative colours and positive sensitizings *can* in fact be such as to overlook any relation

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whatever to what we might expect to be the normal appearance of colours in the negative. By this is meant that the negative colours need not be complementary to the colour of the light recorded. (See below.)



NON SHADED AREAS REPRESENT THE PROPER WAVE LENGTH INTERVALS FOR SENSITISING OF POSITIVE.

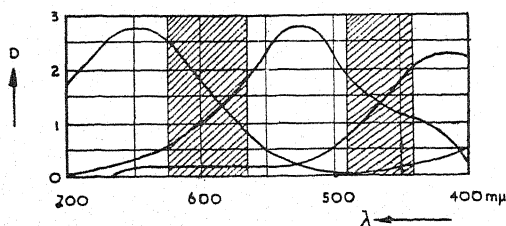


Fig. 195.—Actual dye images available for colour-photography; density versus wave length.

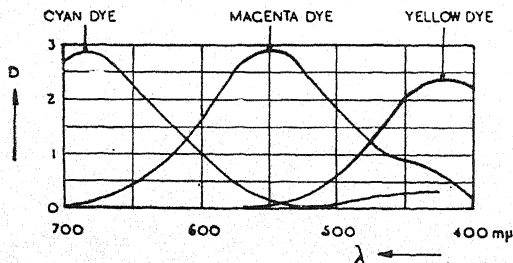


Fig. 195A.—Negative Emulsion Dyes showing Satisfactory Results for Colour Reproduction.

The negative cyan coupler in the present product has remarkable absorption in the deep red and by placing the red sensitivity of the positive far into the red we are assured of the cyan layer of the negative

being efficient to modulate this layer only (Fig. 195A). Thus the relation between negative and positive can be expressed as follows:

Negative.

Fixed Factor .. Spectral Sensitivity
Variable Factor .. Absorption Curves of Colour Components

Positive.

Fixed Factor .. Absorption Curves of Colour Components
Variable Factor .. Spectral Sensitivity

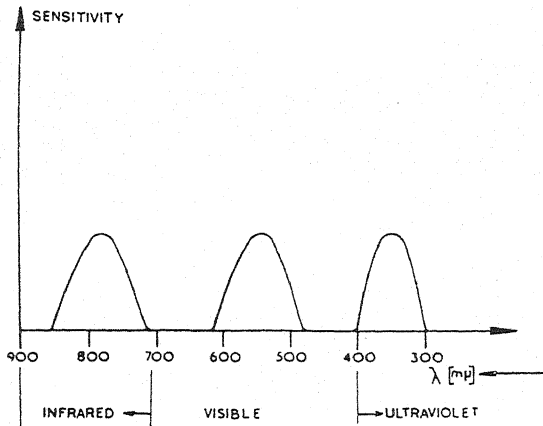


FIG. 196.—Positive Film with widely Separated Sensitization Curves.

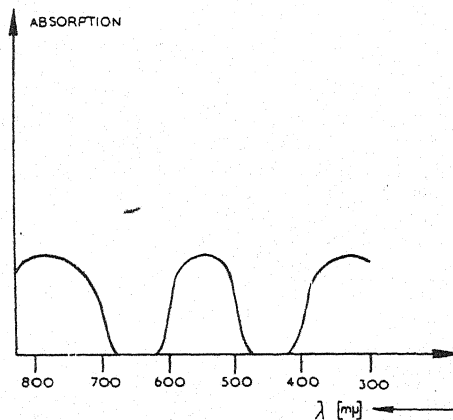


FIG. 197.—Dye Absorption Curves of Negative Film corresponding to the Positive Sensitization Curves shown in Fig. 196.

Schneider and others have suggested that there is no reason theoretically why a positive material should not be sensitized, say, in the

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infra-red, green, and ultra-violet regions, respectively, in order to obtain a more complete colour separation (Fig. 196). In this case the absorption maxima of the three dyes present in the layers of the negative would also have to be in the infra-red, green and ultra-violet (Fig. 197). A dye that absorbs only in the infra-red or in the ultra-violet would be colourless to the dye. Such negative material would be magenta only. Nevertheless, the positive material would "see" a grey scale in the negative as "neutral."

Processing

The development of Agfacolor negative or positive film requires only minor modifications of the standard machines. We have to

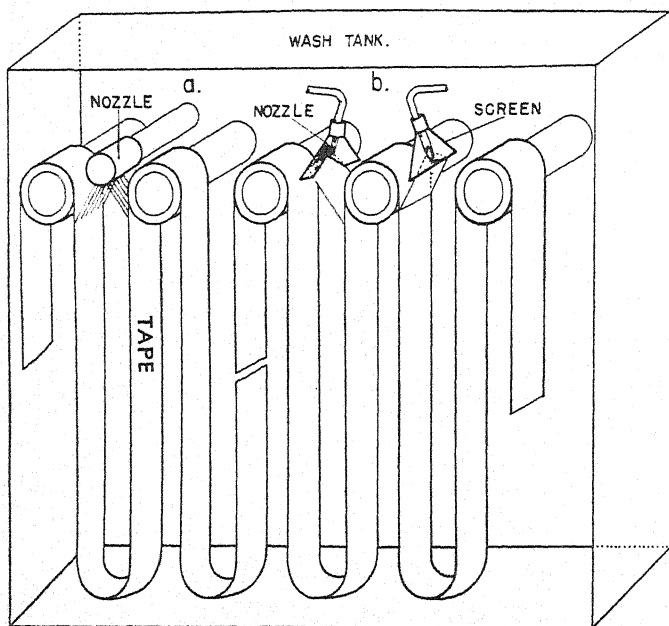


FIG. 198.

provide for a bleaching bath and for washing for a more prolonged period than usual. It is recommended that washing should be entirely carried out by fine jets, or better still by the use of a flat jet issuing from an inclined flattened nozzle.

The developer must be maintained at 18° C., a tolerance of half a degree in either direction being permissible. Schneider states that the solution "is first driven through a device where it is cooled slightly

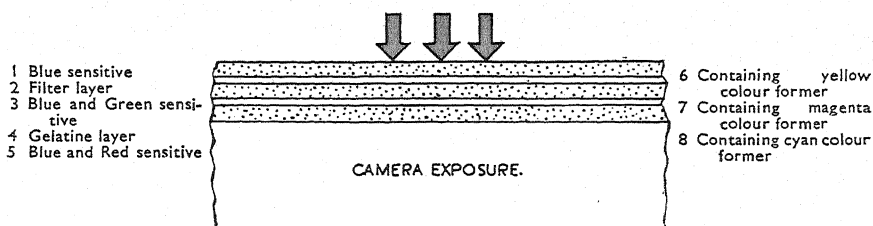


Diagram assumes an exposure is being made to a red object on a black ground.

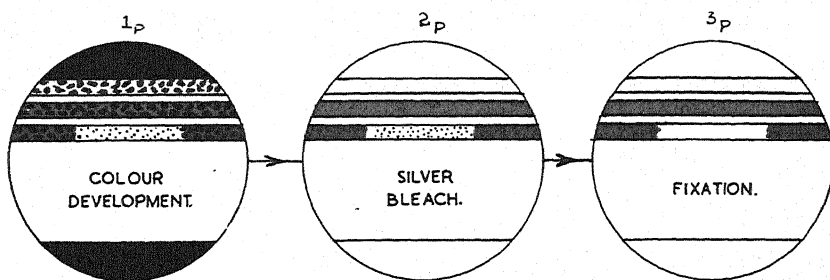
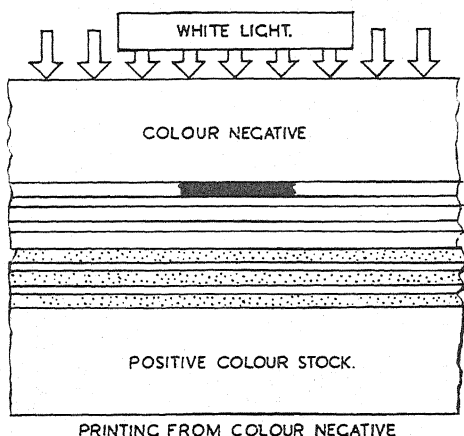
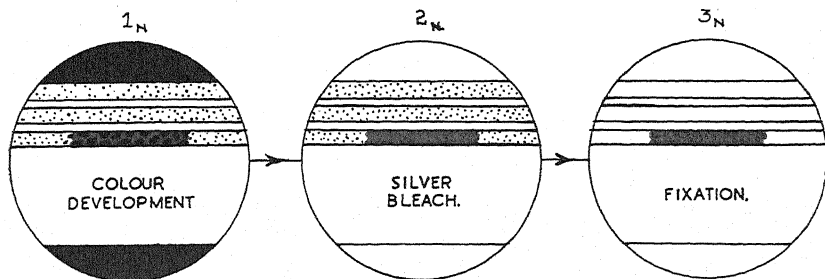
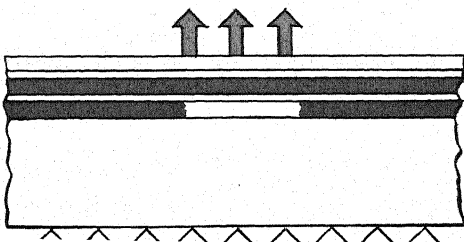


FIG. 198A.—Negative-positive Agfa-color processing sequence. A cross-section of the film is shown at each main processing stage. Washes, rinses and stop baths are omitted.



below the working temperature, water from the mains being used for cooling. Afterwards the solution is again brought to the prescribed working temperature, this being done by means of electric heaters and a thermostatic regulator. The simplest layout consists in inserting this apparatus in the developer circuit, otherwise the developer must be strongly agitated to ensure uniform development."

Plastic materials have been found satisfactory for pumps, and in general, plastics have stood up well for piping and tanks.

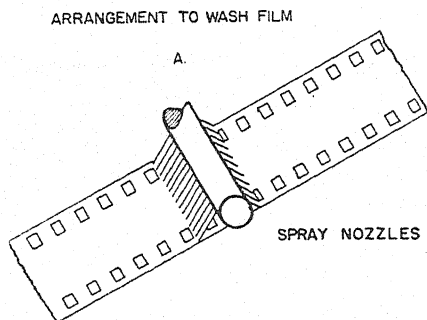


FIG. 199.—Agfacolor Processing Spray Nozzles.

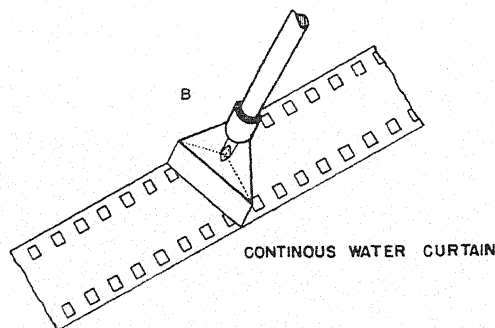


FIG. 199A.—Agfacolor Processing. Alternative curtain nozzle for washing.

Precautions must be taken to prevent the formation of foam in circulated solutions to avoid rapid ageing of baths by oxidation.

Subsequent to development the washing must be very thorough otherwise a general blue fog will be formed in the bleaching bath if the washing is inadequate. It is absolutely essential that hypo should be completely removed in the final wash. Tanks and tubes have been entirely abandoned for washing at any stage. Figs. 198 and 199 show the type of spray wash recommended.

COLOUR CINEMATOGRAPHY

The bath sequences of negative and positive are respectively:

<i>Negative.</i>	<i>Positive (dye sound track).</i>	<i>Positive (silver track).</i>
1. Colour development.	1. Colour development.	1. Colour development.
2. Spray wash.	2. Stop bath.	2. Stop bath.
3. Bleaching.	3. Spray wash.	3. Spray wash.
4. Spray wash.	4. Bleaching.	4. Weak bleach.
5. Fixing.	5. Spray wash.	5. Bleach eliminator.
6. Spray wash.	6. Fixing.	6. Spray wash.
	7. Spray wash.	7. Final bleach (viscous).
		8. Spray wash.
		9. Fixing.
		10. Final wash.

Subsequent to the first spray wash, or in any case after the bleaching bath the remainder of the processing can be carried out in ordinary illumination.

The explanation of the inclusion of a stop bath in the positive sequences is that there is some advantage to be gained from the fact that the developer remaining in the layers continues to be active during the washing, but whereas the developer is soon exhausted in the fully exposed areas the shadows still retain a sufficient supply of fresh developer which continues to produce silver and dye images. The resulting slight fog is of no consequence in the case of the negative film. In the positive film the highlights must be free from fog, and so the action of the colour developer must be interrupted immediately after development. For this purpose acid salt solutions are suitable, for in spite of the permanent addition of alkaline colour developing solution they retain their hydrogen ion concentration at a pH value of 4 to 5, for some time. At the same time, by virtue of the formation of easily dissolved salts the developing agent is washed off more quickly.

It should be noted that when a silver sound track is desired it is necessary to use an additional and preliminary weak bleach to eliminate the colloidal silver yellow filter layer before applying the final viscous bleach on the picture area (see below). This can be done with a weak bleach which is not strong enough to affect any of the silver in the sound track image.

Furthermore it is desirable to include a brief immersion in a five per cent. solution of sodium sulphite *immediately after the final bleach*, to inhibit its action before it has a chance to flow over on to the sound track during the spray wash which succeeds the bleaching bath.

Viscous Bleach

The bleach bath is a preparatory stage in the removal of the developed metallic silver entirely from the dye image. Having formed a silver salt, such as silver ferrocyanide, it is easily eliminated by the solvent action of hyposulphite. Simultaneously the unexposed silver halide is eliminated.

The conventional photocells in use in most projector sound reproducing systems are of the type using a sensitive coating of caesium—silver—oxygen, which is mainly sensitive to red and infra-red radiation. The dyes used in colour development processes transmit radiation in this region, with the result that a dye track is unsatisfactory when used in conjunction with a large proportion of the phototubes used today. While new photocells have been recently developed having high sensitivity in the green-blue and blue regions of the spectrum, and with these dye tracks are capable of reproduction equalling in quality that of silver tracks, it is nevertheless desirable for the time being to continue to employ the silver image sound track. The German solution of this problem was ingenious. Obviously the silver track must not be bleached if it is to be retained. The bleaching agent, potassium ferrocyanide, is therefore mixed with a suitably viscous agent and coated only on the picture area of the film. The bleaching solution (see formula below) is applied to the film from beneath, using a nozzle. This nozzle is supported in such a manner that any join, or film clips, will not jam. The discharge orifice is a little narrower than the picture area and the width of the coating is limited by two movable edges, "pressed against the side edges of the picture area, small lead weights being used for this purpose." By this device accurate separation between picture and sound track has been consistently retained. There is the obvious advantage of using film travel in the vertical direction for the bleaching stage, and thus saving laboratory floor space. The yellow colloidal silver layer is destroyed in the bleaching bath and it follows therefore that it will remain in the sound track. Its presence has been found to be of no consequence provided that the present red sensitive photocells are employed. Should the sound track, however, be intended for use with the new caesium-antimony blue sensitive photocells it is necessary to destroy the colloidal silver yellow layer by the use of a weak bleaching agent which has no effect upon the silver of the sound track image. Subsequently the final viscous bleach may be employed to remove the silver in the picture area as we have described.

Control of Developer Potential

Very rigid control was instituted in the Continental laboratories which processed Agfacolor negative-positive motion picture film. At the Afifa laboratory in Berlin the developer from the time of preparation was analysed and corrected if necessary. After 24 hours rest a new analysis indicated whether there was cause for further correction. The bath was analysed twice a day.

The analytical method of control has been described thus by Schneider: "The content of colour developing agent is determined by colorimetric methods, the agent, together with 1-naphthol-4-sulphonic acid being oxidized to a blue dye by ammoniacal copper sulphate

COLOUR CINEMATOGRAPHY

solution. The potassium carbonate is titrated with $n/1$ hydrochloric acid using methyl orange as an indicator. The sodium sulphite content is determined by titration with $n/10$ iodine solution with soluble starch as an indicator. The potassium bromide is titrated with $n/10$ silver nitrate and $n/10$ ammonium thiocyanate, ferric-ammonium sulphate serving as an indicator. The hydroxylamine content is measured volumetrically by oxidation with potassium ferrocyanide."

PROCESSING FORMULÆ

All baths strictly at $18^{\circ} \text{C.} \pm \frac{1}{2}^{\circ}$

Negative Developer or Positive Developer

Solution A.

Di-sodium salt of ethylene diamine tetra-acetate (M23) (Trilon B)	100	grams
Hydroxylamine HCl	120	"
N-diethyl <i>p</i> -phenylenediamine sulphate	275	"
Water	50	litres

Solution B.

M23	100	grams
Potassium carbonate (anhyd.)	7,500	"
Sodium sulphite	200	"
Potassium bromide	250	"
Water	50	litres

For use take equal parts A and B.

Regenerator Negative or Positive Developer

For Solution A.

M23	100	grams
Hydroxylamine HCl	250	"
N-diethyl <i>p</i> -phenylenediamine sulphate	400	"
Water	50	litres

For Solution B.

M23	100	grams
Potassium carbonate (anhyd.)	7,500	"
Sodium sulphite (anhyd.)	50	litres

Add 15 c.c. per cine metre.

Bleaching Bath. Negative Film only

Potassium phosphate (primary)	58.1	grams
Sodium phosphate (secondary)	42.8	"
Potassium ferricyanide	1,000	"
Water	10	litres

SUBTRACTIVE PROCESSES

Bleaching Bath. For Positive Colloidal Silver Yellow Filter Layer

Potassium phosphate (primary)	..	..	..	..	58.1	grams
Sodium phosphate (secondary)	..	..	..	..	42.8	"
Potassium ferricyanide	..	..	..	..	1,000	"
Water ..	..	..	..	..	10	litres

For use dilute 1 : 20.

Bleaching Bath (Viscous). For Positive Film only

"Colorcoll" (oxymethyl cellulose)	..	..	..	..	60	grams
Potassium ferricyanide	..	..	..	..	100	"
Water ..	..	..	..	..	1	litre

The viscous bleach is applied to the *picture area only* and is used when a silver sound track is desired. In order to prevent the bleaching agent from attacking the silver present in the sound track owing to flow-over during the subsequent wash, the film should next enter a 5% bath of sodium sulphite. Surface squeegeeing methods have also been employed to remove the bleach before washing.

Fixing Bath

Sodium thiosulphate	..	..	..	..	200	grams
Water ..	..	..	..	..	1	litre

Stop Bath (Positive only)

Sodium phosphate (primary)	..	..	..	..	100	grams
Water ..	..	..	..	..	1	litre

Bath Consumption (per 1,000 metres of 35-mm. processed)

Developer Regenerator	..	..	..	..	15	litres
Stop Bath	..	..	..	..	100	"
Bleaching Bath for negative film	..	..	..	..	67	"
Bleaching Bath for yellow filter in positive film	..	..	..	..	143	"
Fixing Bath	..	..	..	..	143	"
Viscous Bleach	..	..	..	..	15	"

Chemicals required per 1,000 metres

N-diethyl <i>p</i> -phenylenediamine sulphate	..	..	..	..	0.06	kg.
M23	..	..	..	..	0.03	"
Hydroxylamine HCl.	..	..	..	..	0.04	"
Potassium carbonate (anhyd.)	..	..	..	..	1.1	"
Sodium sulphite (anhyd.)	..	..	..	..	0.03	"
Potassium phosphate (primary)	..	..	..	..	0.04	"
Sodium phosphate (secondary)	..	..	..	..	0.3	"
Potassium ferricyanide	..	..	..	..	6.7	"
Sodium thiosulphate	..	..	..	..	30.0	"

COLOUR CINEMATOGRAPHY

DEVELOPMENT TIME-TABLE. AGFACOLOR NEGATIVE AND POSITIVE

<i>Treatment.</i>	<i>Negative.</i>		<i>Positive with dye track.</i>		<i>Positive with silver track.</i>	
	<i>Time (Mins.)</i>	<i>Total Time (Mins.)</i>	<i>Time (Mins.)</i>	<i>Total Time (Mins.)</i>	<i>Time (Mins.)</i>	<i>Total Time (Mins.)</i>
Developing	6	6	10-11	10	10-11	10
Stop Bath	omit		2	12	2	12
Spray Wash	15	21	15	27	15	27
Weak Bleach	omit		omit		5	32
Bleach eliminator ..	omit		omit		2	34
Spray Wash	omit		omit		3	37
Bleach Bath	4-5	25	5	32	omit	
Viscous Bleach	omit		omit		5	42
Spray Wash	5	30	5	37	5	47
Fixing	5	35	5	42	5	52
Final Wash	20	35	20	62	20	72
Dry	—	—	—	—	—	—

16-MM. AGFACOLOR REVERSAL FILM

DEVELOPMENT TIME-TABLE

<i>Step.</i>	<i>Description.</i>	<i>Daylight or Tungsten Types.</i>	<i>Reversal Copying.</i>
		<i>Minutes.</i>	<i>Minutes.</i>
1	Amidol Development	35	20
2	Washing	25	25
3	Neopan Bath	5	2
4	Exposure	5	5
5	Washing	2	3
6	Colour Development	11	16
7	Washing	25	25
8	Bleaching Bath	5	5
9	Washing	5	5
10	Fixing	5	5
11	Washing	10	5
12	Bleaching (2nd Bleach)	10	5
13	Washing	5	5
14	Fixing	5	5
15	Washing (Final)	18	15
TOTAL:		171	146

SUBTRACTIVE PROCESSES

PROCESSING FORMULÆ

First Developer	Amidol	5 gms.
	Sodium Sulphite (anhyd.)	50 „
	Potassium Bromide	1 „
	Sodium-hexa-meta-phosphate	0.5 „
	Water	1 litre
Temperature 18° C I ₂ °		
Neopan Bath	Nekal BX (I.G. Farben Wetting Agent)* ..	55 gms.
	Water	1 litre
Colour Developer	N-diethyl <i>p</i> -phenylenediamine sulphate	2.75 gms.
	Hydroxylamine (HCl)	1.2 „
	Potassium carbonate	75 „
	Sodium sulphate	2 „
	Potassium Bromide	2.5 „
	Di-sodium salt of ethylene diamine tetra acetate (M23)	2 „
	Water	1 litre
Temperature 18° C I ₂ °		
Bleaching Bath	Potassium phosphate (Primary) KH_2PO_4 ..	6 gms.
	Sodium phosphate (Secondary) Na_2HPO_4 ..	4 „
Temperature 18° C I ₂ °	Potassium Ferricyanide	100 „
	Water	1 litre
Fixing Bath	Sodium Thiosulphate	200 gms.
	Water	1 litre

* Nekal BX = Alkyl naphthalene-sulphonic acid (sodium salt).
(Wetting Agent 1075.)

Printing

Normal contact or optical printers may be employed; all existing apparatus is therefore usable, but minor modifications must be incorporated in order to make provision for colour grading. In all colour processes in which the print is made in one operation from a coloured negative there must inevitably be two factors to control:

1. Density.
2. Colour balance.

The first factor is controlled by the intensity of the printing light as in printing black-and-white.

The second factor is controlled by varying the distribution of energy in the spectrum of the printing illuminant.

It is the second factor which necessitates the introduction of additions to existing apparatus, since the most convenient means of modifying the spectral character of the light is by the automatic introduction of minus red, minus green and minus blue filters into the illumination system. The introduction of a minus filter may obviously reduce the total energy of the printing light and therefore have an effect upon the general density of the print. Hence in printing colour films such as Dufaycolor or Agfacolor the two factors are interrelated.

COLOUR CINEMATOGRAPHY

In general it is impracticable to control the light energy by the introduction of a resistance in the lamp circuit since this alters the temperature of the filament with important effects upon the distribution of energy radiated. The effect of this will be tantamount to the introduction of a colour filter and the results will be too complex to predict with accuracy. It is essential accordingly to keep the voltage over the lamp fixed within severe limits and to use filters only for altering the volume of light in different regions of the spectrum.

The minus filters should have absorption curves closely similar if not identical to the dyes used in the layers of the *positive* film, thus there can be established a simple relation between the dyes used in the negative film and those of the filters, *i.e.*, the colour density of the filter can be added to the colour-densities of the negative, or the density of the required filter can be determined from colour density which the negative may lack.

The filters may be used in combination, each filter reducing the exposure of a certain layer of the positive. The colours of the filters will then have the same meaning or sign. Thus a yellow filter corrects a yellow hue, and a blue filter, composed of a cyan and a magenta, corrects a blue hue.

The range of filter densities was determined by the following method: a yellow, a magenta and a cyan filter are combined and the light source identical to the printing source viewed through the combination. The respective densities of the filters are altered until a neutral grey is obtained having a density of 1.0. The three filters so determined are arbitrarily assigned a value of 100. The values of all the other filters are decimal fractions of the calibration filters.

Six figures are employed. The first two designate the concentration of the yellow filter, the middle two that of the magenta filter, and the last two figures refer to the cyan filter. For example, 30 90 means: no yellow filter, a 30 per cent. magenta filter and a 90 per cent. cyan filter. These figures can be added or subtracted.

If the filter set-up of a negative has been found for a positive film which is neutral, and this negative has to be printed subsequently on a positive material which is "out of balance," the two filter values may be added, the filter value of the positive material being determined by exposing a step wedge through colour filters—

$$\begin{array}{rcl}
 \text{Thus: Negative filter value} & 40 & 00 & 20 \\
 \text{Positive filter value} & 00 & 10 & 10 \\
 \hline
 & & & = 40 & 10 & 30 \\
 & & & & -10 & 10 & 10 \\
 \hline
 \text{Neutral print filter value} & & & = 30 & 00 & 20
 \end{array}$$

When changing over to a new positive batch, the filter value of this material has to be subtracted, for example:

SUBTRACTIVE PROCESSES

Neutral print filter value	30 00 20
Filter value for new positive material	—10 00 10
New filter value	= 20 00 10

Usually 10 steps of each filter colour are ample, but occasionally 5 per cent. steps are used. Thus 30 filters comprise a complete set. A set of filters of the values 10, 20, 30 and 50 would yield every possible combination.

The Continental laboratories made use of the well-known Debric diaphragm strip. In this machine the volume of light is controlled by means of circular holes in a paper strip. The filter foils are attached over the holes with light metal clips. The size of hole controls the total light volume or a neutral grey may be added to the colour filter (Fig. 200).

In practical printing filter numbers for each scene must be ascertained by direct testing. Experience showed that with a single frame light change covering every combination, the most satisfactory grading system was to provide a ribbon control carrying not only a series of diaphragm widths but also all combinations of the filter numbers 30, 60 and 90 consisting of 47 frames for ten diaphragm steps:

Filter Combinations

Diaphragm Steps.

<i>O</i>	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>	<i>V</i>	<i>VI</i>	<i>VII</i>	<i>VIII</i>	<i>IX</i>	<i>X</i>
30 00 00			30 30 00			30 00 30			00 30 30	
60 00 00			60 30 00			60 00 30			00 60 30	
90 00 00			90 30 00			90 00 30			00 90 30	
00 30 00			30 60 00			30 00 60			00 30 60	
00 60 00			60 60 00			60 00 60			00 60 60	
00 90 00			90 60 00			90 00 60			00 90 60	
00 00 30			30 90 00			30 00 90			00 30 90	
00 00 60			60 90 00			60 00 90			00 60 90	
00 00 90			90 90 00			90 00 90			00 90 90	

From the developed test print, the most neutral frame can be selected with ease, and from the diaphragm series the optimum printing light can be determined. Next on a fine control ribbon all combinations are recorded in ten steps centred on the most neutral setting. For a rough filter value of 60 60 00 these values are:

				30 60 00
40 40 00		40 50 00		40 60 00
50 40 00		50 50 00		50 60 00
60 40 00		60 50 00		60 60 00
70 40 00		70 50 00		70 60 00
80 40 00		80 50 00		80 60 00
				90 60 00
40 70 00		40 80 00		
50 70 00		50 80 00		
60 70 00		60 80 00		
70 70 00		70 80 00		
80 70 00		80 80 00		

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The ten members of this series are arranged in a step order of $\sqrt[3]{2}$. This gives a series of ten densities in steps of 10.

Colour Correction

The writer is unaware of whether or not it is the practice to correct the colour balance of a motion picture print by a subsequent bath intended to *reduce* one of the three subtractive primaries. For the sake of completeness we give below data extracted from "The Agfacolor Process" by Wilhelm Schneider.

Reduction of the dyes, he says, "has its inherent drawbacks as the overall density of the picture will be decreased, the shadows becoming more transparent and in some cases even coloured." This is a curious statement because shadows will in most circumstances be coloured anyhow: he is probably referring to *blacks*. He continues: "The solutions given offer a correction for every possible type of colour error." He proceeds to state that while the yellow and cyan are reducible independently, unfortunately the magenta reducer acts upon the yellow and cyan also but less actively. If the excess is red, green or blue, then baths must be successively used of yellow and magenta reducers, cyan and yellow, or magenta and cyan.

1. Excess Yellow Reducer

Sodium cholate (not chlorate)	50	grams
Water	1	litre

Time 2-5 minutes depending upon density in excess. Watch the action with great care. Wash after completion for 20 minutes. Discoloration of the bath does not reduce the activity.

2. Excess Magenta Reducer

Solution A.

<i>m</i> -Aminoaniline hydrochloride (re-crystallized from water)	3	grams
Water	100	"

Solution B.

Borax	30	grams
Water	1	litre

For use, 30 c.c. of Solution A are made up to 100 c.c. with water, and then used in equal parts with Solution B.

3. Excess Cyan Reducer

Sodium Carbonate (anhyd.)	0.2	grams
Acetanilide	0.4	"
Water (hot)	100	"

Darkroom Illumination

No safelight is desirable in the case of negative. Apparently two filters are occasionally employed for a brief period should operation

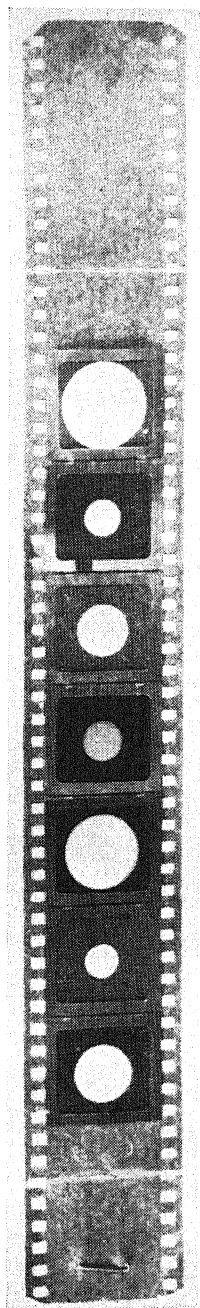


FIG. 200.—Debie light-control and colour-grading strip.

(Facing p. 376)

demand it. For direct illumination Agfa No. 170 and for indirect Agfa No. 108. Both are green filters with maximum transmission at 530 $M\mu$, the density at this wavelength being 3.2.

The sensitizing of the positive film shows two gaps, at roughly 510 $M\mu$ and 590 $M\mu$. The latter position was selected for the maximum transmission of the safelight filter, owing to high sensitivity of the retina in this region, and resolving power is also higher than for red or green light. It is better to have high visual acuity in the darkroom than high illumination. While filters can be made which transmit light of a narrow wavelength band in the yellow region they are not efficient. It is recommended to use sodium vapour discharge lamps giving the familiar monochromatic radiation of 589 $M\mu$. The intensity is too high for safety and the lamps are used with a filter having an absorption band in this region. These safelights must be mechanically air-cooled. Using two filters of 20 \times 30 cm. and a suitable curved reflector, large rooms can be uniformly lighted. The safety margin for Agfacolor positive is 30 minutes.

General Remarks

The German technicians do not seem to have used a special illuminant in printing machines. A system of combination of light sources such as has been successfully used for the printing of Dufaycolor would seem to present valuable advantages. This consists in the mixture of light given by: A. a 500-watt projector lamp used with a narrow-cut red filter, and B. a mercury vapour discharge lamp used in conjunction with a Didymium glass filter which serves to absorb the yellow lines of the mercury emission spectrum, and also to absorb wavelengths in the blue-green region. The combined radiation consists of:

Narrow wavelength band	..	670 $M\mu$ —600 $M\mu$	(Red)
Monochromatic wavelength band	..	546 $M\mu$	(Green)
	..	436 $M\mu$	(Blue-violet)
" (with certain " lesser blue lines of the mercury spectrum)			

If required a filter may be added to absorb the high-energy ultra-violet radiation.

In Britain a suitable discharge lamp is manufactured by Siemens Bros. and Co. Ltd.

LAMP DATA

Mercury discharge lamp (special direct current type)

<i>Watts.</i>	<i>Cap.</i>	<i>Diameter.</i>	<i>Length Overall.</i>	<i>Light centre above lugs of pre-focus cap.</i>	<i>Voltage.</i>
		<i>mm.</i>	<i>mm.</i>	<i>mm.</i>	
125	Pre-focus	50	185	115	200/210 377

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This lamp has now been standardized and its relative output of radiation should be constant after the lamp has been run continuously for 75 hours. During this ageing period it is quite possible that the line spectral emission ratio varies to a minor extent, but no data is available.

It is proposed by Dufay-Chromex Ltd. to experiment in the printing of Agfacolor positive using Agfacolor negative with such a light source, and data will be published at an early date. On theoretical grounds there are good reasons to expect a marked improvement over the previously employed system.

Emulsion Coating and Sensitizing Data

The following manufacturing data are summarized for reference purposes, but the reader is referred to the FIAT FINAL REPORT 943 of the Office of Military Government, U.S., for full details. Published by the U.S. Department of Commerce, Technical Industrial Intelligence Division (Table 58).

TABLE 58.—SENSITIZED LAYERS IN AGFACOLOR FILMS

<i>Agfacolor Material.</i>	<i>Layer.</i>	<i>Emulsion Type and No.*</i>	<i>Sensitizer.</i>	<i>Coupler.</i>
Reversal, day-light	Anti-halo Bottom	Black (00812a) " Noodles " 3 parts " Process Colour " (111/378e) plus 2 parts " T-film fine grain " (00710)	Rr 2632	— F 654 Koe 308
	Middle	As above, but 2 parts and 3 parts respectively	Rr 340 Kt 945 }	Z 169
	Filter	" Filter Yellow Extra " (00814)	—	
	Top	1 part " Sound-film IV " (00263) plus 2 parts " Phototechnic A III " (00513)	—	F 535
Reversal, half-watt	Anti-halo Bottom	As before 1 part each " Sound-film IV " and " T-film fine grain "	Rr 2632	— F 546 F 654 }
	Middle	As for bottom layer ..	Rr 340 Kt 945 }	Z 169
	Filter	As for daylight	—	
	Top	" " " " " " ..	—	F 535
Reversal, copy film	Bottom	2 parts " Middle layer colour " (00716e) plus 1 part " Colour Positive " (00717f)	Rr 1953	— F 546 F 654 }
	Middle	As for bottom layer ..	Rr 340	Z 169
	Filter	As for daylight	—	
	Top	4 parts " Positive-Tobis " (00117) plus 1 part " Colour " (00708d) ..	—	F 535

SUBTRACTIVE PROCESSES

TABLE 58.—*continued.*

<i>Agfacolor Material.</i>	<i>Layer.</i>	<i>Emulsion Type and No.*</i>	<i>Sensitizer.</i>	<i>Coupler.</i>
Non-reversal types B-2 (daylight negative) for miniature sizes, cut film, roll film, and 35-mm. Cine	Bottom	"Isopan fine-grain Colour" (111/381a) ..	Ma 1088	F 654
	Middle	"Middle-layer colour" (00716e) ..	Rr 340 Rr 1650 Rr 1523	Z 169
	Filter	As before	—	—
	Top	4 parts "Positive-Tobis" (00117) plus 1 part "Colour" (00708d)	—	F 535
G-2 ($\frac{1}{2}$ -watt negative) for miniature films, cut film, roll film, and 35-mm. Cine	Bottom	As for daylight	Ma 1088	F 654
	Middle	" " " " " "	Rr 340	Z 169
	Filter	" " " " " "	Rr 1650 Rr 1523	
	Top	"Isopan" fine-grain Colour" (111/381a) ..	—	F 535
Positive Film for 35-mm. Release Printing	Bottom	1 part "Colour Positive Ia" (00717f) plus 1 part "Atopan" (00715d) ..	Rr 1953	F 546
	Middle	As for bottom layer ..	Rr 340	Z 169
	Filter	As before	—	—
	Top	4 parts "AIII" (00513) plus 1 part "Standard Emulsion" (111/401a) ..	—	Ta 521
Agfacolor Paper: From U.S. Report	Bottom	"Brovira Soft"	Ma 2116	F 546
	Middle	" " " " " "	Rr 340	F 542
	Filter	"Filter Yellow Extra" ..	—	Koe 302
	Top	"Brovira Soft"	—	F 535

* See Table 59.

TABLE 59.—
(Courtesy of the British

Procedure.	111/378e	111/381a	111/401a	00117	00263
I. Water .. (li.)	80.25	44	80	130	48
KBr .. (kg.)	10.676	9.5	5.5	20.12	9.2
KI .. (kg.)	0.256	0.230	0.225	0.350	0.24
NaCl .. (kg.)	—	—	—	1.72	—
Gelatine .. (kg.)	1.15	2.5	0.75	5.2	1.8
II. No. of lots ..	2	2	1 each	1 each	1 each
(a) Water .. (li.)	43.84	44	22.5	103.5	72
AgNO ₃ .. (kg.)	6.40	6.25	2.25	10.35	10.3
NH ₄ OH (0.91) (li.)	—	6.25	—	—	10.3
(b) Water ..	—	—	52.5	103.5	12
AgNO ₃ ..	—	—	5.25	15.52	1.7
NH ₄ OH, etc. ..	—	—	—	—	1.7
III. Gelatine (kg.) dry	15	12.5	20	43.4	12
F-10, etc. ..	0.64	—	—	—	—
MgO or CaCO ₃ to ..	neutral	—	neutral	neutral	—
Precipitation, deg. C. ..	70 deg.	36.5 deg.	67 deg.	61 deg.	?
Solution/vol./time (min.)	II/28 li./1½	II/25 li./2	{ IIa/22½ li. } { IIb/22½ li. } 1	IIa/3 min.	IIa/0
Interval (min.) ..	—	4	—	—	10
Solution/vol./time ..	II/28 li./1½	II/25 li./2	—	IIb/11 min.	IIb/0
Interval ..	—	4	15	(B)	18
Solution/vol./time ..	II/rest/29	II/25 li./2	IIb/rest/20	—	—
Interval ..	—	4	—	—	—
Solution/vol./time ..	—	II/rest/1	—	—	—
Addition of III ..	Yes	Yes	Yes	Yes	Yes
Digestion time (min.) ..	10	30	2	30	(Set for 2 hr.)
Additions/setting time ..	—	A	(cooling)	(Set 70 min.)	—
Conductivity ..	1,800/F 4	1,600/F 4	1,800/F 4	1,802 2,403 after ripening	1,802/F 4 2,563 melted 2,622 ripened
After ripening:—					
Gelatine (kg.) ..	10.0	7.25	—	—	8.65
MgO to ..	—	No. 6	—	—	—
F 5 (li.) ..	0.66	0.72	0.7	—	—
F 7 ..	—	—	—	0.725	—
F 8 ..	0.25	—	0.25	0.32	—
F 10 ..	2.15	1.2	—	—	—
10% KBr. (li.) ..	—	0.84	—	—	0.95
10% Pot. metabisulphite ..	—	—	—	—	—
F 11 ..	—	2.4	—	—	0.2
F 12 ..	2.42	—	—	—	—
F 13 ..	—	—	—	—	—
Time and temp. deg.	—	—	—	—	—
C. extra ..	—	—	45½/50 deg.	—	—
Water (li.) ..	—	—	—	—	—
Acetic acid 1:2 ..	—	—	—	—	—
Apparent final concns. per litre:—					
Gelatine ..	15	12.8	13.2	14	15.5
Silver (as nitrate) ..	7.3	7.1	4.8	7.5	8.25
Iodide/bromide ratio (neglects excess) ..	0.023	0.024	0.041	0.0175	0.026

SUBTRACTIVE PROCESSES

EMULSION CODES

Journal of Photography)

00513	00708d	00710	00715d	00716e	00717f	<i>Brovira.</i>
73.5 7.75 0.176 1.10 3.5	112.5 4.17 0.35 — 0.5	72 5.9 0.36 0.36 1.8	80 5.5 0.265 — 0.7	126 4.71 0.394 — 0.5	128 9.38 0.616 — 1.0	19 3.06 0.125 0.5 NH ₄ Br 4.0
2 55 5.5 — — — —	2 25 5 — — — —	2 54 4.5 — — — —	1 each 33 3.3 — 42 4.2 —	2 28 2.8 — — — —	1 each 74 7.4 — 46 4.6 —	1 each — — 0.5 50 5 0.1125 NH ₄ NO ₃
16.5 — —	13.5 — neutral	16.5 — —	20 — neutral	20 — —	32 — neutral	3.75 12 li. water —
61 deg. IIa/44/0 2 II/rest/17 — — Yes	70 deg. II/37.5 li./2 — II/rest/46 — — Yes	69 deg. II/56.6 li./1 30 II/rest/20 (62 deg.) — — Yes	66 deg. IIa/all IIb/33 li. } 1 IIb/rest/20 — — Yes	70 deg. II/40.4 li./2 8 II/rest/30 — — Yes	68 deg. IIa/all/1 — IIb/all/23 — — Yes	42 deg. IIa/all/0 — IIb/all/0 20 at 48 deg. — — Yes
30 (Set 90 min.)	2 (Set 2 hr.)	36 (Set 1½ hr.)	2 (Set 70 min.)	8 (Set 1½ hr.)	2 (Set 70 min.)	20 at 48 deg. —
1,602/F 4 1,955 melted 1,955 ripened	1,802/F 4	2,508/F 4	1,802/F 4 1,860 ripened	1,802/F 4	1,802/F 4 2,884 ripened	1,800
— — — — — — — — 1.85 — — —	8.0 — 0.6 — 0.21 — — — — — — —	— — — — — — — — — — — —	— — 0.7 — 0.25 — — — — — — —	10.0 neutral 0.75 — 0.3 — — — — — — —	— — 1.2 — 0.4 5.7 — — — — — —	9.0 — — — — — — — — — — — 50/75 deg. 60.0 0.275
10.9 6 — 0.023	13.6 6.2 — 0.083	10.2 5 — 0.06	13 4.8 — 0.048	16.8 3.1 — 0.07	13 4.7 — 0.066	11.8 3.5 — 0.041

COLOUR CINEMATOGRAPHY

TABLE 59A.—COATING DATA

Layer.	Melting temp.	Interval between filtering and coating.	Coating temperature.		
			Pos.	Neg.	Rev.
Gelatine ..	50° C.	60 mins.	35° C.	—	—
NC ..	50°	—	35°	35°	35°
Black ..	50°	60 mins.	—	—	35°
Bottom ..	50°	Pos. 120 mins. Neg. 90 „ Rev. 60 „	33°	35°	35°
Middle ..	45°	45 mins.	33°	40°	40°
Filter ..	Pos. 45° Neg. 65° Rev. 65°	60 „ 60 „ 60 „	40°	60°	60°
Top ..	Pos. 50° Neg. 50° Rev. 65°	60 „ 60 „ 60 „	40°	40°	40°
Overcoat ..	Rev. 50°	60 „	—	—	35°

Material.	Layer.	Ag in mgms./dm.	Thickness.
Negative	Bottom	34	8.7—9.5 μ
	Middle	8.4	6.4—7.5 μ
	Top (type B-2)	17.2	6.0—7.0 μ
	„ (type G-2)	19.8	6.1—6.3 μ
Positive	Bottom	14.8	5.5—6.5 μ
	Middle	11.4	4.4—5.5 μ
	Top	24.8	8 —9 μ

Coupler.	Amount and final concn.	Initial Solvents.	Final Solvents (to 150 litre).	Final pH.
F 546	7.5 kg. (5%)	Water .. 75 litre	Water	9.5
F 654	4.5 „ (3%)	N-NaOH .. 5.26 „	„	9.8
		NaOH .. 9.45 kg.		
		Methanol .. 4.5 litre		
		NaOH .. 0.75 kg.		
Ko 308	15 „ (10%)	Water .. 1.5 litre	Methanol	9.1
Z 120	7.5 „ (5%)	N-NaOH .. 19 „	Water	10.1
Z 169	7.5 „ (5%)	„ .. 20.25 „		9.0
F 535	4.5 „ (3%)	„ .. 16.2 „		10.1
Ta 521	4.5 „ (3%)	„ .. 81.0 „		10.5
		Nekal BX (20%) .. 18.0 „	„	
	or: 15 kg. (10%)	NaOH .. 1.125 kg.	Methanol	10.3-10.6
		Water .. 2.5 litre		

Rr 1953

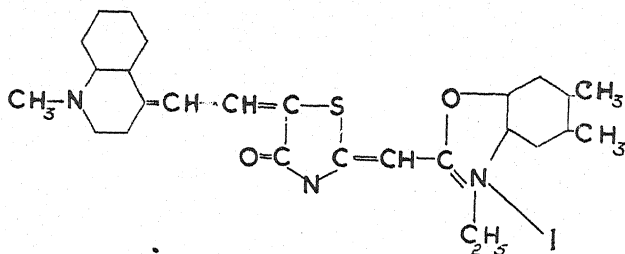


FIG. 205.—Positive Sensitizer. Bottom layer.

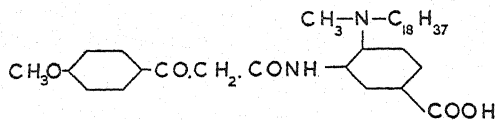


FIG. 206.—Colour Coupler for Negative and Positive.

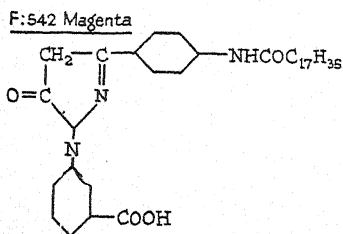


FIG. 207.—Colour Coupler for Positive.

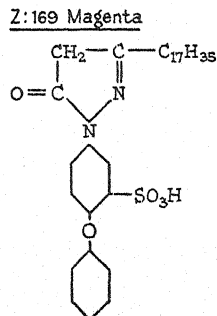


FIG. 208.—Colour Coupler for Negative.

KOE 302 MAGENTA.

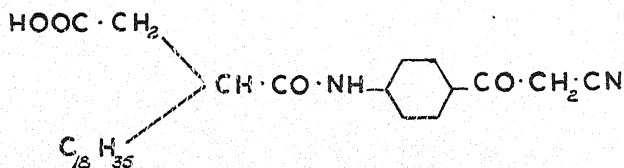


FIG. 209.—Colour Coupler for Positive.

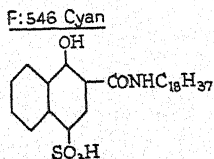


FIG. 210.—Colour Coupler for Positive.

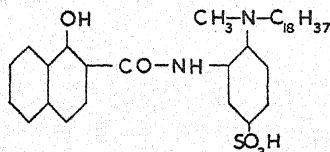


FIG. 211.—Colour Coupler for Negative.

LIMITS OF ACCURACY IN COLOUR REPRODUCTION ATTAINABLE WITH THE AGFACOLOR PROCESS

The FIAT FINAL REPORT NO. 977, published by the Office of Military Government for Germany (U.S.) is entitled "Color Reproduction by Color Photography," by Dr. Paul Keck, formerly of Zeiss. This is a very interesting report upon some colorimetric work carried out in Germany on reproduction deviations found in the reproduction of colours by the Agfacolor films. After a review of modern colorimetric methods, he sums up the mathematical formulation of the problem of colour photography by A. C. Hardy, F. L. Wurzburg and others, in this next statement.

"There is an unambiguous mathematical relation between the reception sensitivities and the chromaticities of the primaries according to which perfect colour reproduction can only be theoretically achieved by the use of two assumptions: either to apply a set of realisable sensitivity curves, in which case the corresponding primaries turn out to lie outside the spectrum locus, or to assume a set of realisable primaries, in which case the sensitivity functions will then involve sections of negative values which are unrealisable."

The theoretical accuracy of reproduction achievable with various primaries have been computed for an additive process by W. Schultze and H. Hoermann of Agfa, Wolfen. Dr. Keck quotes from an unpublished paper by these authors. They calculated the reproduction of three different sets of samples:

1. The Oswald eight full colours.
2. Eight saturated pigment samples from the Baumann-Prase Atlas.
3. Eight spectrum wavebands of constant luminance.

The reproduction which would be given by 22 different sensitivities (possible or impossible to realize), including linear shapes, parabolic shapes, tristimulus values of the spectrum, Hardy and Wurzburg's positive values only.

Generally the tristimulus values give the worst results. The best results for the eight full colours are given by linear shaped ranges (rectangular sections) as follows:—419-485 $M\mu$, 503-574 $M\mu$, 574-640 $M\mu$, with an average distance on the RUCS diagram of 0.017; for the pigments 0.019.

For the eight full colours the best sensitivity was given by Hardy and Wurzburg's curves, representing positive parts only of the tristimulus values but separated by vertical joins. Here the RUCS distance was only 0.013, and for the pigments 0.016.

Summarizing, Schultze and Hoermann state:

1. Sensitivities with large overlapping spectral curves give poor reproduction. This is especially true for the tristimulus values of the spectrum used as sensitivities.

2. Sensitivity curves calculated according to Hardy and Wurzburg give very good results if the negative parts, as well as the overlapping sections, are neglected.
 3. The reproduction is almost as good as before when optimum colours are used which do not cover the whole visible wavelength range.
 4. No essential differences between the reproduction of optimum colours and pigments occurred.
 5. Spectrum colours do not result in good reproduction.
 6. The best colour reproductions result in average deviations from 0.013-0.020 in the RUCS system.
 7. Red and magenta chromaticities in general give rise to the largest differences and yellow hues correspond to the smallest ones.
- These computations refer to an additive process.

The same authors have published measurements on colour reproduction by Agfacolor reversal film of a set of 12 highly saturated filters. The illuminant was ICI—C¹ using Agfacolor Reversal Daylight Type. The filters were also reproduced on Agfacolor Reversal Tungsten Type. This film must be viewed with a source of 2,840° K. Dominant wavelength and colorimetric purity of the originals and reproductions were measured. The colorimetric purity values were transformed into excitation purity. For the 12 selected samples the dominant wavelengths and excitation purities are given in the accompanying Table 60. The values under D1 and D2 refer to two exposures in daylight and A refers to the exposure to tungsten light.

TABLE 60

Colour Filters.	Dominant Wavelength in Mμ.				Excitation Purity.			
	Original.	D1.	D2.	A.	Original.	D.	D2.	A.
a	600	589	598	585	0.85	0.54	0.48	0.63
b	586	580	590	578	0.73	0.68	0.65	0.71
c	574	580	580	577	0.82	0.74	0.68	0.73
d	549	566	563	562	0.72	0.64	0.55	0.64
e	538	566	563	559	0.61	0.57	0.54	0.58
f	517	553	551	510	0.53	0.44	0.42	0.35
g	496	498	510	493	0.54	0.25	0.19	0.50
h	487	493	495	503	0.61	0.25	0.25	0.16
i	430	—556	—555	—524	0.86	0.29	0.30	0.60
k	—558	—505	—505	—496	0.81	0.42	0.44	0.49
l	—521	—508	—509	—498	0.91	0.40	0.38	0.51
m	648	602	602	599	0.48	0.32	0.39	0.43

The distortions are serious, especially with blue and violet hues. As far as luminance is concerned the transparency of the reproduction is always less than that of the original filter.

¹ C.I.E.

The same authors measured the reproduction chromaticities of the same 12 filters as reproduced by the Agfacolor negative-positive process and also obtained comparison reproductions by printing Agfacolor positive with three separation negatives exposed through Agfa tricolor filters 40, 41 and 42. The light source was ICI—A. Narrow-cut tricolor filters were used for printing. The reproduction of blue and violet filters i, k and l, display larger deviation than did the reversal film. The print made from the separation negatives was little better. The RUCS average distance was 0.097 for the negative-positive and 0.066 for the three separation negative method.

Eight pigments of high saturation in the Baumann-Prase Color Atlas were reproduced by the reversal and by the negative-positive process. Results are given in the following Table.

TABLE 61

<i>Test Pigments.</i>	<i>Dominant Wavelength in Mμ.</i>			<i>Excitation Purity.</i>		
	<i>Original.</i>	<i>Reversal.</i>	<i>Neg.- Pos.</i>	<i>Original.</i>	<i>Reversal.</i>	<i>Neg.- Pos.</i>
1. Red	614	597	598	0.67	0.66	0.65
2. Orange	595	592	593	0.85	0.65	0.63
3. Yellow	576	578	578	0.69	0.65	0.44
4. Yellow-Green	570	573	565	0.63	0.50	0.33
5. Green	529	563	505	0.26	0.32	0.15
6. Blue-Green	495	554	490	0.23	0.17	0.23
7. Blue	472	481	481	0.71	0.34	0.36
8. Purple	—549	627	—521	0.40	0.12	0.08

Note the dominant wavelength of No. 8 has changed from that of a purple to a red (very desaturated), excitation purity having fallen from 0.40 to 0.12. No. 1 has become more orange. The reproduction of No. 5 by negative-positive is far more blue-green than by reversal. On the other hand No. 6 is nearly matched by negative-positive and badly out in reversal.

In general, the Agfacolor process gave deviations about twice as great as by the best an additive system could yield. Reversal was slightly superior to negative-positive.

Dr. Keck poses the question, "How large do the chromaticity and luminance deviations of the reproductions *have to be*, compared with the original, in order to produce the most natural sensation under given projection conditions?" Since he points out, quite correctly, that for projection it is undesirable that a film should be an exact colorimetric reproduction, owing to the physiological and psychological conditions involved. This is an interesting question and there is not much data yet to help us to come to reliable conclusions.

Summary

The weakness of processes employing an original record *in colour* lies in the difficulty of making duplicate master negatives without obtaining unacceptable degradation or distortion of colour and/or loss of resolving power. Masking is a pastime for mathematicians. The writer is firmly convinced that up to the present, a set of separation negatives represents by far the most reliable and accurate foundation. Beam-splitter cameras are expensive, cumbersome, and delicate, but they give the technician an odd feeling of security after experience of the vagaries of monopak. Nevertheless negative-positive processes, such as Agfacolor, have their proper field of application and we must hope that one of the manufacturers will shortly revive its production. In the meantime physicists are welcome to cover pages with their symbols to prove that something can be done on paper which cannot be done in the laboratory.

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- "Another F.I.A.T. Report on Agfacolor," *Brit. Journ. Phot.*, **114** (Feb. 14, 1947), p. 70.
- "The Agfacolor Negative-Positive Processes," *Brit. Journ. Phot.*, **113** (July 26, 1946), p. 263.
- "How to Make Agfacolor Film," *Brit. Journ. Phot.*, **114** (Oct. 31, 1947), p. 399.
- Note: B.I.O.S.=British Intelligence Objectives Sub-Committee.
C.I.O.S.=Combined Intelligence Objectives Sub-Committee.
F.I.A.T.=Field Information Agency, Technical (U.S.A.).

Anso Color.¹

(Manufactured by Ansco, Binghamton, N.Y., U.S.A., a Subsidiary of The General Aniline and Film Corporation.)

Classification.—Integral tripack three-colour reversal subtractive process, the emulsion layers incorporating non-diffusing colour couplers.

Camera.—Normal.

Projection.—Normal.

Printing.—Normal. With suitable means for grading for colour.

Processing.—Normal machinery with adaptations. See below for full description.

TYPES OF ANSCO COLOR FILM FOR MOTION-PICTURE CAMERAS

<i>Width.</i>	<i>Type.</i>	<i>Speed Rating.</i>	<i>Illumination.</i>
16 mm.	Reversible Type 235	<i>Weston. G.E.</i> 8 12	Daylight Type
16 mm.	Reversible	12 16	Tungsten Type. 3,200° K. or No. 2 Photoflood

		<i>Weston. G.E.</i>	<i>Purpose.</i>
35 mm.	Reversible Type 735	5 8 (ASA 6)	<i>Camera Recording.</i> Gradation softer than 16 mm. Finer grain. Colour balance deliberately off neutral Daylight balance, for H.I. Arcs filtered with Y.1 gelatine or Tungsten Lamps filtered with Macbeth "Whiter-lite" Glass. On Nitrate Film Base.
35 mm.	Reversible Type 835	Ditto	Ditto, but coated on Acetate Film Base
35 mm.	Reversible Type 732	2 to 4 times light needed for B. & W. fine grain Positive	<i>Release Positive Printing.</i> Nitrate Film Base.
35 mm.	Reversible Type 832	Ditto	Ditto. Acetate Film Base
35 mm.	Reversible Type 132	Ditto	<i>Duplicating Film</i>

¹ Data presented by kind permission of the manufacturers.

COLOUR CINEMATOGRAPHY

Types of Ansco Color Film.—*cont'd.*

ANSCO ONE-STRIP COLOR-SEPARATION FILM

<i>Width.</i>	<i>Type.</i>	<i>Speed Rating.</i>	<i>Purpose.</i>
35 mm.	Type 155 Black-and-white	Equal gammas for Red, Green and Blue exposures	For separation negatives from original reversal colour positives comprising intermediate stage in preparation of black-and-white positive masters for printing on Ansco Release Positive Film Type 732

General Description.

Ansco Color Reversible 16 mm. film was first made for use by the United States Services after the entrance of U.S. into the war. The structure of the film is substantially identical to the Reversal Type German Agfacolor film, the full manufacturing data of which were naturally at the disposition of the pre-war Agfa Ansco Corporation. Subsequent to the war 16 mm. Ansco Color film was made generally available to the public, and in 1945 three types of Professional 35 mm. Ansco Reversible Film were announced, including a duplicating film and positive film for release prints. Special processing machinery has been constructed, and machinery has been installed in commercial laboratories.

The range and accuracy of colour reproduction is excellent, although somewhat lacking in saturated reds due to the magenta coupler yielding a somewhat desaturated hue. All types so far available are designed for reversal processing. First and second generation dupes, of fair quality, have been made.

This process is an important addition to the choice of colour films available to the motion picture industry. It is probable that a negative-positive process, similar to Agfacolor, will later be introduced. Fig. 212 illustrates the now familiar processing sequence.

Structure.

Nitrate or Cellulose Acetate safety film base coated with three emulsion layers (excluding a yellow filter layer of colloidal silver and the anti-halation coating) selectively sensitized to three spectral regions, red, green and blue. The outermost emulsion is blue sensitive, next comes an interlayer of colloidal silver comprising a yellow filter to prevent further penetration of blue light, the middle emulsion is green sensitized, the bottom emulsion is red sensitized and with little or no green sensitivity. The base is coated with an anti-halation backing of colloidal silver beneath the bottom layer of emulsion (Fig. 212A).

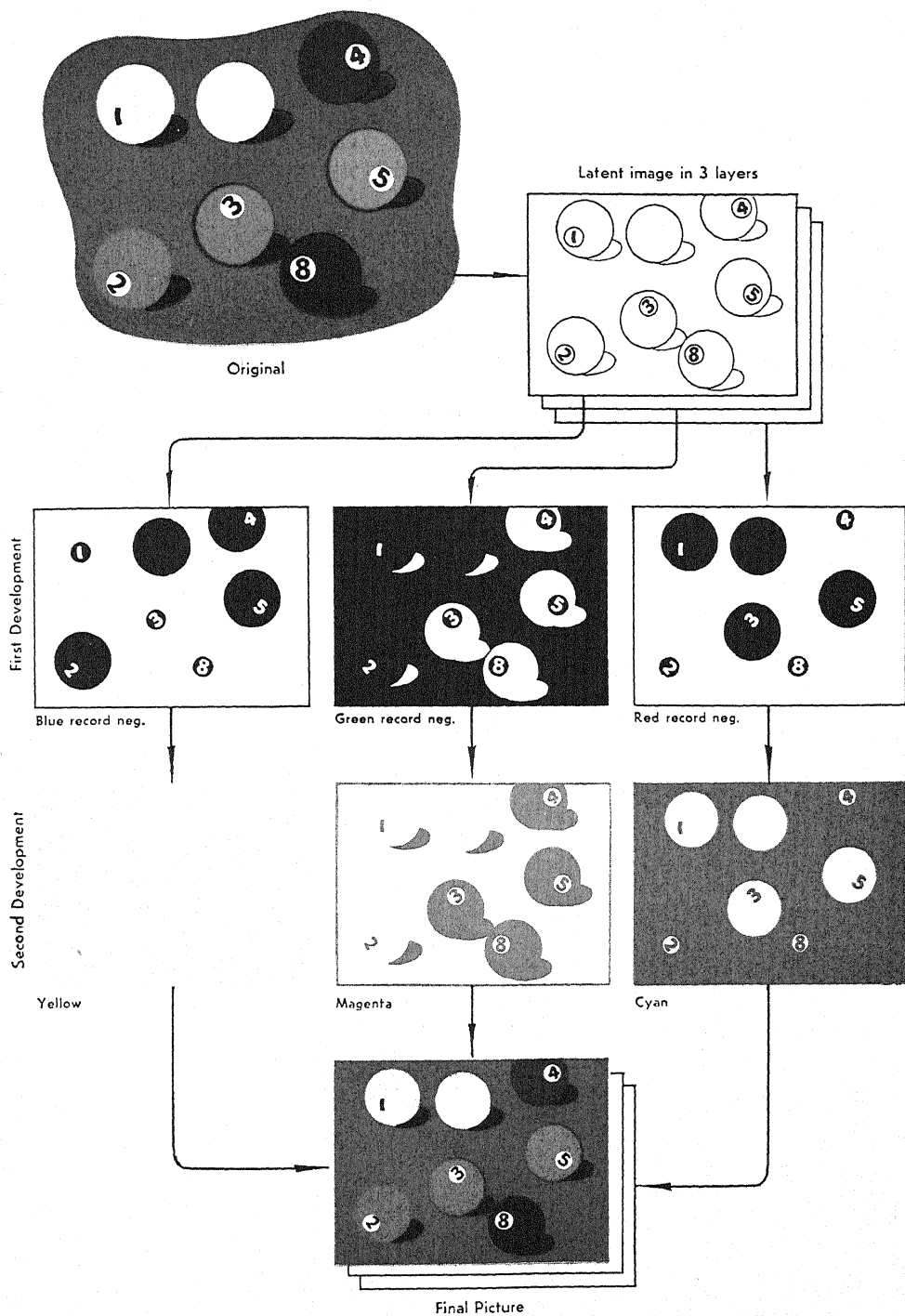


FIG. 212.—Ansco color reversal film processing sequence.

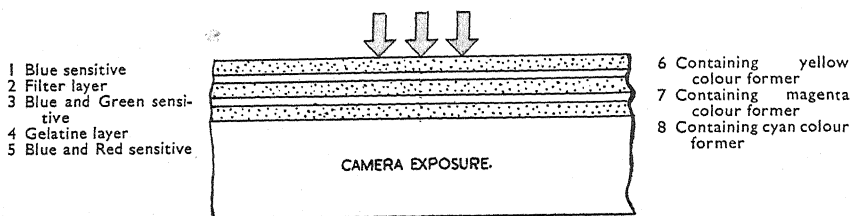


Diagram assumes an exposure is being made to a red object on a black ground.

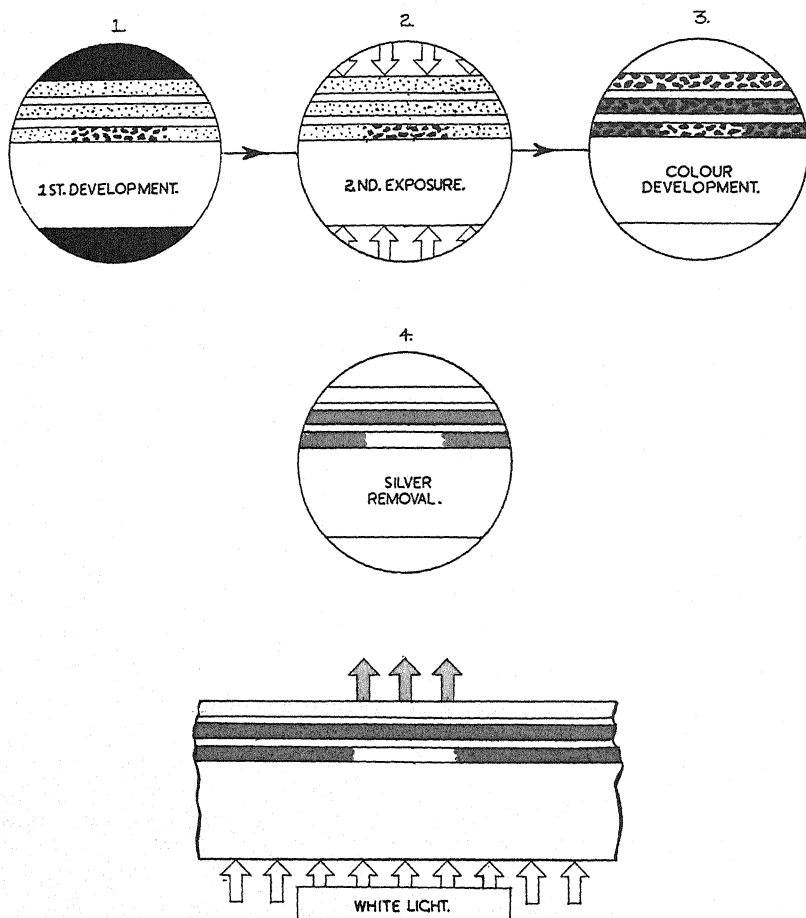


FIG. 212A.—Ansco color reversal film. Structure and mode of image formation.
[Facing p. 391]

SUBTRACTIVE PROCESSES

The colour couplers are subtractive to the gelatine emulsions in which they are dispersed, their non-diffusion characteristic being achieved by the addition to the couplers of long chain fatty acids. Similarly the sensitizers are non-diffusing.

The camera film is sensitized without a break through the visible spectrum, the maximum sensitivity being at 650 $M\mu$, 550 $M\mu$ and 440 $M\mu$. The positive has sharp sensitivity peaks and a complete break at 575 $M\mu$. The red sensitivity is continued much further into the red than with the camera film, the maximum being at 680 $M\mu$. For the reasons for the adoption of the special characteristics of the positive sensitizing see the section on Agfacolor (p. 363).

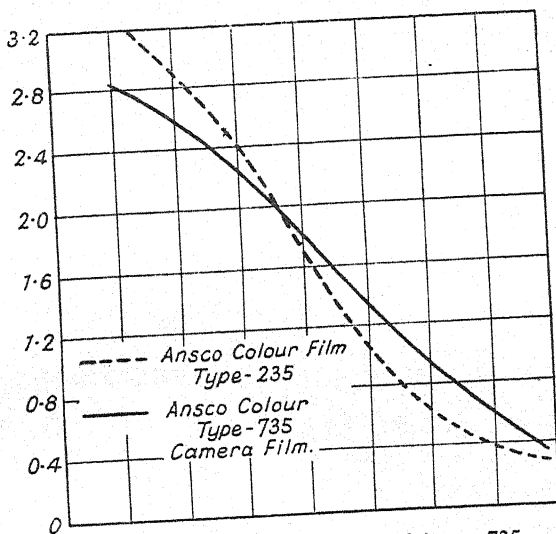


FIG. 213.—Characteristic Curves of Ansco 735.

Ansco Color 35 mm. Camera Film.

As the 35 mm. process is at present restricted to the use of reversal films at all stages, the camera original record is therefore a positive when processed. The characteristics of the 35 mm. camera recording film have been modified as compared with a film intended to be used for projection such as Ansco 16 mm., with the object of meeting the requirements of printing first and second generation duplicates with the minimum loss of colour saturation and accuracy of colour reproduction. Ansco Color Type 735 is softer in gradation compared to regular Ansco Color Film, the grain is finer and the colour balance purposely set off-natural. Fig. 213 shows a comparison of the characteristic curves of Ansco Color Type 735 and Ansco Color Daylight Film Type 235.

COLOUR CINEMATOGRAPHY

Anso Color Camera Film is available on both nitrate and acetate film base and designated 735 and 835 respectively. The former is balanced for exposure in bright sunlight; or for studio exposures, the key-light should be provided by H.I. carbon arcs modified by Y-1 gelatine filters and fill-light by tungsten lamps (3,200° K.) filtered with Macbeth Whiterlite glass. The spectrogram shown in Fig. 214 gives the relative response of the film to the visible region of a daylight spectrum.

For optimum print results the film should be slightly underexposed or somewhat heavier in density than is the normal practice when exposing for screen projection of an original, in order to maintain as much of the exposure as possible on the straight-line portion of the

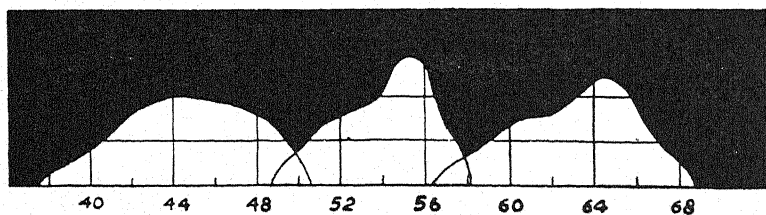


FIG. 214.—Wedge spectrogram of Anso Color Camera Film, Type 735 (H. H. Duerr and H. C. Harsh).

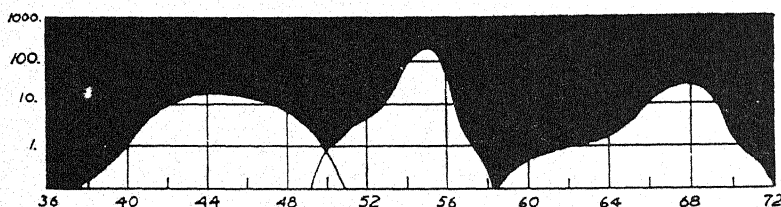


FIG. 215.—Wedge spectrogram of Anso Color, Type 732 Release Film (H. H. Duerr and H. C. Harsh).

characteristic curve and avoid inaccurate colour reproduction from exposures falling in the region of the toe. This film should be processed for a somewhat shorter time in both first and colour developer than in the times given for 16 mm. processing.

Printing.

Release printing is catered for by Anso Color Release Film Type 732, characterized by low speed, very fine grain, and by sensitizing showing sharp peaks in the green and red regions and a partial gap between these peaks, ensuring maximum colour separation. Release film is available on both nitrate and acetate film designated 732 and 832 respectively (Figs. 215, 216).

SUBTRACTIVE PROCESSES

Printing machines should possess the following features:—

1. A light source which operates at a colour temperature of approximately $3,000^{\circ}\text{K}$.
2. A means for inserting printing filters into the light path quickly.

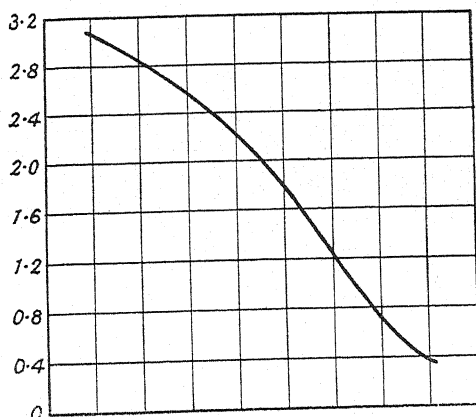


FIG. 216.—Characteristic Curve of Ansco Type 732.

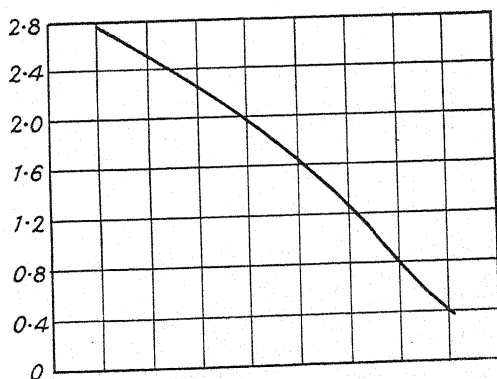


FIG. 217.—Characteristic Curve of Ansco Duplicating Film.

3. A condenser lens system for the light source to concentrate the light at the aperture. Ansco Color Release Film, with the printing filters in place, will require 2 to 4 times the light needed for printing black-and-white positive fine grain stock.
4. It is good practice to provide an air blast or fan as a means of dissipating the heat from the lamp house in order to avoid damage to the filters and film.

A standard series of colour compensating filters in a range of densities of yellow, magenta and cyan, are available.

Prints from Duplicates.

Dupes are essential where special effects such as lap dissolves and wipes have to be introduced and also to provide a master dupe for release printing. Two methods have been devised.

1. Optical printing of the Ansco Color original on to Ansco Color Type 132 Duplicating Film.

This stock has about the same speed as Type 732 (Release Print). Processing is identical to Type 735 (original camera film). This first generation duplicate can then be interspliced with the original and used for release printing on Ansco Color Type 732 Release Film. The characteristic curve of this film is shown in Fig. 217.

Developing time for Type 132 is 10 minutes for first developer and 9 minutes for colour developer.

There is some loss of colour saturation in the second generation duplicate by this method, but the loss is not serious enough to preclude its use for certain lap dissolves, wipes, and other special effects if perfect colour rendition is not essential. The method is not recommended for making full-length master dupes. For this purpose the second method is preferred.

2. Optical printing of Ansco Color Film Type 735 on to Type 132 masked with a black-and-white film which has been contact printed from the original Type 735 camera film. The masking film is designated Type 154. A special low-shrink, panchromatic, black-and-white film has been developed for making masks. This is a low contrast film, its characteristics being illustrated in Fig. 218.

In order to ensure good registration, the same printing equipment should be used for the printing of this colour correction mask which later on is used for the printing of the masked master dupe. Suitable optical printers must possess synchronized intermittent movements with register pins and good optical equipment (Fig. 219).

To make the mask it is run in contact with the original in the camera head of the optical printer, using the projection head empty as a source of light. A yellow filter is placed in front of the source of light.

The mask is developed in a negative developer of normal type.

To print the master dupe the original is run in the projection head optically registered to the mask now placed in the *camera head*. It is then printed in contact with Ansco Color Type 132 Duplicating Film.

Naturally accurate optical registration must be checked before printing can begin. Special effect matter should be run in the projection head with the original.

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This method, it is claimed, will yield a conformed master dupe that will show little or no colour saturation.

The masked master dupe is finally used for printing release prints on Ansco Color Type 732 Release Film in a regular continuous printer equipped with mechanical means for the insertion of compensating filters (see above).

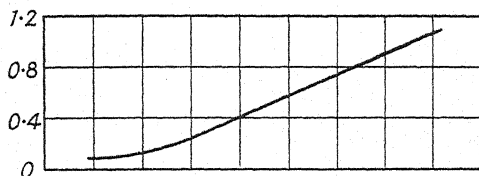


FIG. 218.—Characteristic Curve Ansco Masking Film.

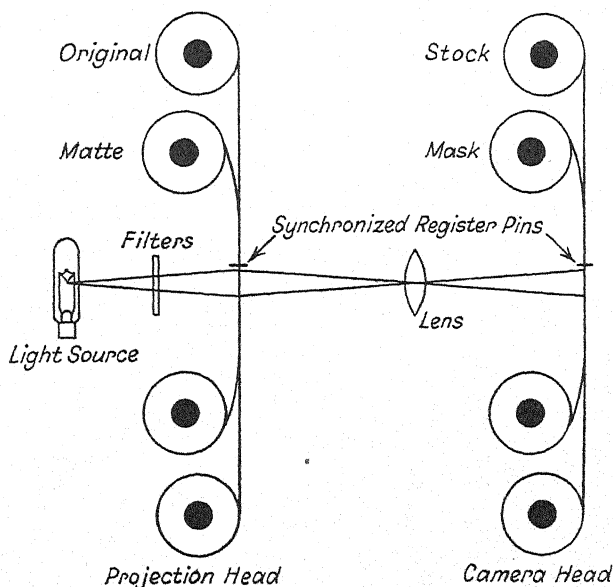


FIG. 219.—Schematic view of optical printer.

Ansko One-Strip Color-Separation Film.¹

In 1946 Ansco announced a new monochrome film designated Ansco One-Strip Color-Separation Film, Type 155. It has the special property of giving identical gamma for red, green and blue recordings in the same development time. This is equally true for low contrast (0.50) and for high contrast (2.00). The cyan dye used in Ansco Color Film

¹ See also page 134.

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has a maximum absorption at approximately 6,800 Å. This enables the use of a Wratten No. 70 filter to yield a red separation that is nearly ideal. It is not feasible to use the No. 70 filter with normal panchromatic film (Fig. 220).

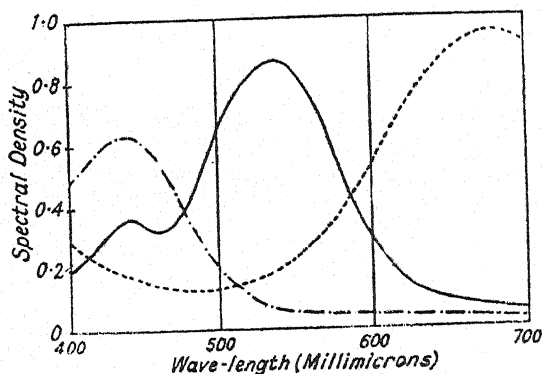


FIG. 220.—Spectrophotometric curves of dyes in Ansco Color, Type 735. (Courtesy of Ansco: H. C. Harsh, J. S. Friedman and *Journ. Soc. Mot. Pic. Eng.*)

The following technique is employed. The scene is photographed on Ansco Color Film Type 735. This is then copied on Type 155 film using a printer which is equipped with registration pins and capable of skip-frame printing. At this stage fades, lap dissolves and other optical

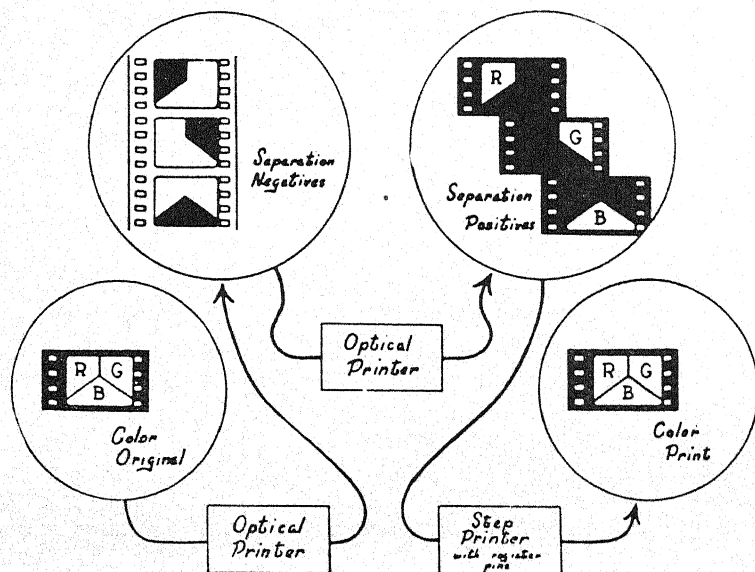


FIG. 221.—Graphic representation of steps involved in using Type 155. (Courtesy of Ansco: H. C. Harsh, J. S. Friedman and *Journ. Soc. Mot. Pic. Eng.*)

effects can be introduced. The Type 155 film is then developed to a gamma of approximately 0.65 in a buffered borax developer of the type used for variable density sound film. The resulting film is now a conformed master containing all the effects and with the colour records as successive black-and-white frames. It serves as a protection against damage to the original.

To convert the separation negatives to colour prints, they are first printed on standard black-and-white Duplicating Positive film on the same optical equipment for making the negatives, and developed to a gamma of approximately 1.4. The final step is to print the separation positives on to Type 732 film three times through the appropriate filters. The result is claimed to be a release print equal in colour reproduction to a direct print from the original (Fig. 221).

This film has been designed to solve the specific problem in the case of monopack materials of avoiding the loss of saturation when it becomes necessary to make second, third or fourth generation duplicates which will yield good release prints.

Sound Track.

Since the release printing stock is a reversible film, a positive black-and-white track is required for printing. The ideal way to obtain such a track would be a direct-positive recording. Equipment for this purpose is not generally available, and the following method is recommended by Ansco.

The recording head of the sound equipment is moved so that the negative recording is obtained on the opposite side of the film. This negative is then printed on to black-and-white positive stock, which will then have the sound track in the proper position for printing directly on to the Ansco Color Type 732 Release Film in the conventional manner.

Dye tracks, especially those obtained by the dye coupling method, have a relatively low absorption in the infra-red region. Thus the conventional infra-red-sensitive photocell, for example, type 868, is not too well suited for these dye tracks and a loss in volume, amounting to approximately 6 db., is encountered. This loss in volume, while serious, still comes within the range where adjustment can be made by fader setting on most 35-mm. projection equipment. The new R.C.A., I.P. 37, a gas-filled phototube, meets the requirements since the sensitivity of its caesium-antimony surface has its peak at 4,200-4,500 Å, being highly sensitive to green and blue. This surface is known as S-4, the existing tubes having the S-1 caesium-silver-oxygen surface with mainly red and infra-red response. Levels are found to be slightly below those from silver tracks. Signal-to-noise ratios are practically the same as with silver tracks.

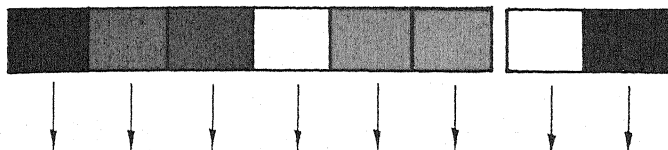
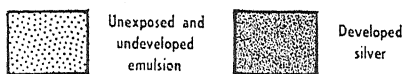
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Two-layer tracks (yellow and magenta) printed on the two upper layers of the tripack have a slightly superior performance as compared with three-layer tracks. Single (yellow) layer tracks are of no use owing to the green sensitivity of the I.P. 37 phototube. Good tracks can be made from either direct positives, or printed masters, provided a good negative is available for making the master. Masters should have higher densities and more image spread for printing colour tracks than for making standard silver tracks, and the control for minimum distortion follows the usual cross-modulation test procedure.

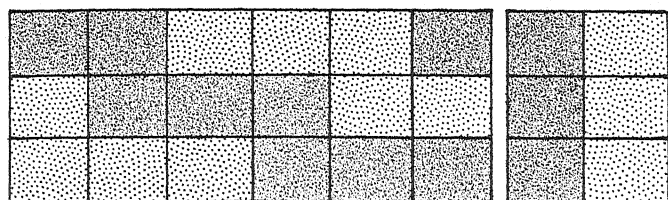
Processing.

The processing of Ansco Color Reversal Film is relatively simple, though there are thirteen steps as against the four involved in developing ordinary black-and-white negative film. The first step is to develop the negative latent images produced by exposure of the film in a camera. This is done in a high-sulphite metol-hydroquinone developer designed to avoid any coupling action between by-products of development and the colour couplers in the three emulsion layers. After immersion in a short-stop bath, and a brief rinse, the film is exposed to the light of a photoflood lamp so that the remaining silver halides of the emulsions are rendered developable. Development is carried out in a solution whose active ingredient is a derivative of paraphenylene diamine,¹ and the by-products of development react with colour formers in the emulsion layers. Following colour development, the film is treated successively in a clearing bath, hardening bath, washed, and then immersed in a bleaching solution. Here the silver of the negative and positive images, as well as the yellow filter layer and anti-halo coating, is converted to silver bromide by the combined action of potassium ferricyanide and potassium bromide. Care must be taken to ensure that bleaching is complete, since the dyes formed during colour development inhibit the action of the bleach solution by preventing its ready access to the particles of metallic silver. After bleaching, the film is washed and fixed in ordinary hypo. A final wash and drying complete the process.

¹ The developing agent in the Ansco Color Developing Outfit is sold under the trade name of "Dicolamine." This is supplied as a liquid, and judging from the formula it is a solution of 4 gm. of diethyl-*p*-phenylene diamine hydrochloride and 1 gm. of sodium bisulphite. Ansco has apparently preferred to use a trade name to designate the developing agent to ensure that only material which is laboratory tested for Ansco Color Film is used. This is quite important, since the degree of purity of the diethyl-*p*-phenylene diamine hydrochloride colour developing substance can greatly influence the quality of the results in regard to colour balance and dye stain.



White is the combination of light of all colours and black is the absence of all colour.

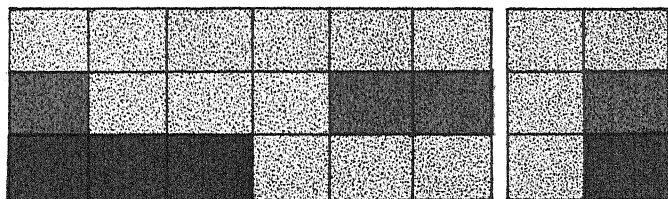


The blue sensitive layer containing the yellow colour component.

The green sensitive layer containing the magenta colour component.

The red sensitive layer containing the cyan colour component.

Exposure records the blue light in the first layer, the green in the second layer and the red in the bottom layer. During the first development black and white images are formed.

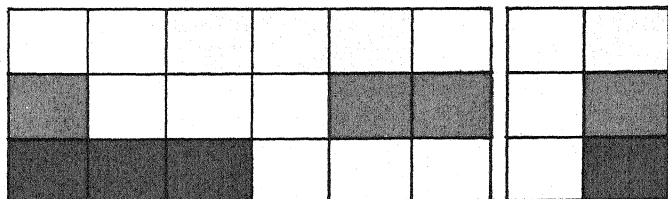


The blue sensitive layer contains metallic silver and yellow image.

The green sensitive layer contains metallic silver and magenta image.

The red sensitive layer contains metallic silver and cyan image.

After washing, the film is exposed to white light and redeveloped. This second development forms both metallic silver and colored images in those portions of the emulsion layers unaffected by the first development.



The blue sensitive layer contains the yellow dye image.

The green sensitive layer contains the magenta dye image.

The red sensitive layer contains the cyan dye image.

All metallic silver formed during both the first and second development is removed by the bleaching bath, leaving only the dye images in the three emulsion layers.



The cyan, magenta and yellow dye images combined reproduce the original colors of the subject.

The three primary coloured dye images (yellow, magenta and cyan) when combined in proper proportions, form neutral greys or black.

FIG. 221A.—Ansco color reversal film processing sequence.

SUBRACTIVE PROCESSES

PROCESSING TIME-TABLE FOR ANSCO COLOR MOTION PICTURE FILM (REVERSAL TYPE)

<i>Treatment.</i>	<i>Time.</i>	<i>Total Time.</i>	<i>Temperatures.</i>
	<i>Min. Sec.</i>	<i>Min. Sec.</i>	
First Development ..	12 —	12 —	68° F. $\pm \frac{1}{2}$ degree.
Short Rinse	— 5	12 5	
Shortstop I	3 —	15 5	68° F. $\pm \frac{1}{2}$ „
Hardener I	3 —	18 5	68° F. $\pm \frac{1}{2}$ „
Wash and 2nd Exposure	3 —	21 5	
Colour Development ..	3 —	24 5	68° F. $\pm \frac{1}{2}$ „
Short Rinse	15 —	36 5	
Shortstop II	— 20	36 25	68° F. $\pm \frac{1}{2}$ „
Hardener II	3 —	39 25	68° F. $\pm \frac{1}{2}$ „
Wash	3 —	42 25	
Bleach	3 —	45 25	68° F. $\pm \frac{1}{2}$ „
Wash	6 —	51 25	68° F. $\pm \frac{1}{2}$ „
Fix	3 —	54 25	68° F. $\pm \frac{1}{2}$ „
Wash	6 —	60 25	68° F. $\pm \frac{1}{2}$ „
Final Wash	5 —	65 25	
	6 —	71 25	

DEVELOPING TIMES

<i>Type.</i>	<i>First Developer.</i>	<i>Colour Developer.</i>
	<i>Minutes.</i>	<i>Minutes.</i>
Anso Color Type 735 or 835	9	11
Anso Color Type 132 or 232	8	9
Anso Color Type 732 or 832	10	18

Automatic Processing Machine for Ansco Color Film.

J. L. Forrest of Ansco describes the sprocketless developing machine which he designed for the processing of Ansco 16-mm. Reversal Film. This description may be assumed to be substantially correct for 35-mm. developing machines also. Bottom-drive mechanism is used. Precision-bored hard-rubber rollers having tracks and recess ensure no contact with picture in sound-track area. There are 25 units in the wet section and 4 units in the drying section. The whole requires more than 5,000 ft. of leader for threading. Seven units are in the dark and 18 wet units in the light. The roller banks are about $3\frac{1}{2}$ ft. between centres and they are mounted 8 in. apart on the top support. The range of speed is from 40 to 72 ft. per minute—normal speed 60 ft. The film is driven by friction applied through the bottom drive. The machine is entirely self-compensating for dimensional change in the film.

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Quoting from Forrest's paper:

"The behaviour of acetate safety film during the developing cycle is rather interesting. There are two factors which influence the dimensional change. One we term the 'Humidity Coefficient,' and this refers to the change of dimension which occurs when the film is subjected to moist air or water. The other factor we term the 'Temperature Factor,' This refers to the change of dimension in the film which occurs when it is subjected to changes of temperature either in air or in aqueous solutions. In processing, the dimensional changes occur continually as the film passes through the developing machine. These changes of dimension, seen in Fig. 222, are ordinarily not noticeable to the eye, but they are appreciable. Very careful consideration must be given

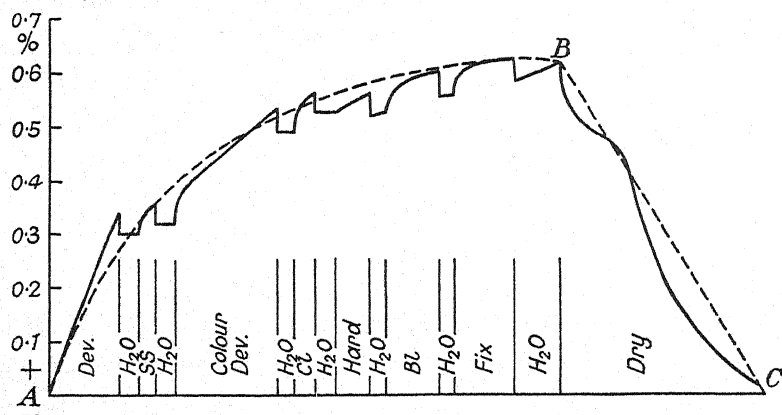


FIG. 222.—Dimensional changes in Ansco film during processing (J. L. Forrest).

to them when designing a developing machine, otherwise the film will run with excessive tension in some sections and be excessively loose in others.

"In order to compensate for these factors, all top rollers of the developing machine are free to move independently of each other. To ensure this, a stationary separator washer is placed between each roller. This permits entirely independent movement of each roller without a tendency drag from neighbouring rollers. This design will permit equalization in the wet section as long as the film is expanding, for it permits each loop of film free movement and slippage. It will not, however, compensate for shrinkage which must occur in the drying operation. In other words, it will take care of the dimensional change in the film, as indicated from point A to point B in Fig. 222. From point B to point C a reverse condition exists and the film becomes shorter. In order to compensate for this reversed dimensional change, the drying cabinet is underdriven,

PROCESSING FORMULÆ FOR ANSCO COLOUR MOTION PICTURE FILM (REVERSAL TYPE)

<i>First Developer</i>								pH 9.8-10
Metol	..	..	..	..	..	..	3 gm.	
Sod. sulphite	..	..	..	..	..	..	50 "	
Hydroquinone	..	..	..	..	..	..	6 "	
Sod. carbonate	..	..	..	..	..	..	40 "	
Pot. bromide	..	..	..	..	..	..	2 "	
Sod. thiocyanate	..	..	..	..	..	..	2 "	
Water to make	..	..	..	..	..	..	1 litre	
<i>Short Stop I and II</i>								pH 5.3-6
Acetic acid (glacial)	..	..	..	..	..	..	5 c.c.	
Sod. acetate	..	..	..	..	..	..	30 gm.	
Water to make	..	..	..	..	..	..	1 litre	
<i>Colour Developer</i>								pH 10.10-3
Sod. bisulphite	..	..	..	..	..	..	1 gm.	
" Colamine "	..	..	..	..	..	..	4 "	
Sod. carbonate	..	..	..	..	..	..	67 "	
Pot. bromide	..	..	..	..	..	..	1 "	
Water to make	..	..	..	..	..	..	1 litre	
<i>Hardener I and II</i>								pH 3.8-4.5
Pot. chrome alum	..	..	..	..	..	..	30 gm.	
Water to make	..	..	..	..	..	..	1 litre	
<i>Bleach</i>								pH 6.2
Pot. ferricyanide	..	..	..	..	..	..	100 gm.	
Pot. bromide	..	..	..	..	..	..	10 "	
Dibasic sod. phosphate	..	..	..	..	..	..	40 "	
Sod. bisulphate	..	..	..	..	..	..	35 "	
Water to make	..	..	..	..	..	..	1 litre	
<i>Fixer</i>								pH 7.3-8
Hypo	..	..	..	..	..	..	200 gm.	
Water to make	..	..	..	..	..	..	1 litre.	

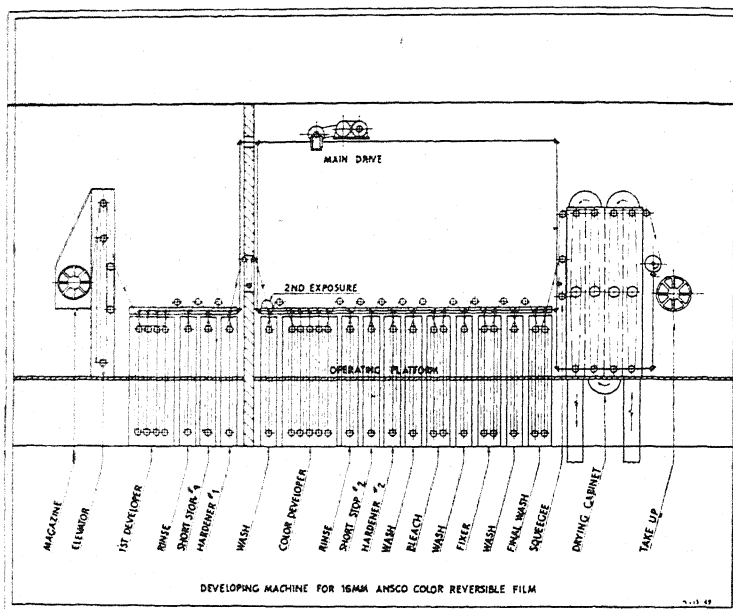


FIG. 223.—Developing Machine for 16 mm. Ansco Color Reversible Film.

which means that more film is drawn into the cabinet than is taken from it. This difference in drive is in relation to the dimensional change which occurs in the film.

" By designing each section of the machine to compensate independently for these dimensional change factors, the tension on any part of the film at any point in the machine never exceeds 30 gm. or 1 ounce. With this low strain on the film, breaks in the machine are extremely rare. We have some machines in continuous operation for more than six months at a time without a film break (Fig. 223).

" All metallic parts of the developing machines coming in contact with the solutions are made of 18-8 stainless steel. The solution tanks are made of steel, rubber coated $\frac{1}{8}$ in. inside and $\frac{1}{16}$ in. on the outside. It has been found that coating the tanks with rubber on the outside reduces the maintenance cost.

" In operation the film is fed into an elevator. The elevator holds about 120 ft. of film. From the elevator the film passes over a break signal device into the first developing tank. There are four roller banks in the first developer giving a total time of 12 minutes at normal operating speed. After developing, the film passes successively into the rinse, the shortstop, the hardener, then through the light lock into white light. At this point it is given a second exposure. The second exposure is supplied by four G.E. PS-25 lamps, two placed on each side of the film.

" Simultaneously with the second exposure the film is given a 3-minute wash and then goes into the colour developer. There are five banks of rollers in the colour developer. This gives a total time of 15 minutes at normal operating speed.

" The next four units of the developing machine are in single tanks to accommodate the steps of rinsing, shortstopping, hardening, and washing. After the film has passed through the hardener and its subsequent wash, it travels into the bleach. The bleach tank accommodates two units and provides 6 minutes at normal operating speed. Bleaching is usually completed in $2\frac{1}{2}$ minutes. The extra time is provided to ensure thorough bleaching. After bleaching, the film passes through a wash tank and then into the fixer.

" The fixer tank contains two units allowing 6 minutes at normal operating speed. This ensures complete removal of the rehalogenated silver. The developing machine is provided with two wash tanks following the fixer. The first tank contains a single bank of rollers and allows 3 minutes of washing. This removes most of the fixer. The second wash tank contains two banks and provides the final wash of 6 minutes. The residual hypo left in the film after processing falls below 0.005 mg. per sq. in., which is satisfactorily low to ensure permanency. After washing, the film passes through a double pneumatic squeegee, operating at 7 lb. pressure, into the drying cabinet.

" There are four banks of rollers in the drying cabinet and drying is accomplished in about 15 minutes. Clean, dry air is supplied to the cabinet from a dehydrator. The drying system is entirely closed and it is automatic in operation. The temperature is maintained at 86° F. and the relative humidity is held at 35 per cent. In this system, if faster or slower drying is desired, the relative humidity is adjusted at the dehydrator. The air temperature is not changed. We have found this method of drying to be very satisfactory from all angles and it can be highly recommended.

" The chemical mixing equipment is located on the floor above the laboratory and the solutions are fed through rubber pipelines to the processing tanks of the machine. All make-up solutions are maintained at approximately the working temperature. This is accomplished by heat transfer coils located in all storage tanks. The temperatures of the processing solutions are controlled within narrow limits.

" In order to ensure sharp, brilliant colour images, the developers, bleach, and the hypo are filtered and jetted against the film as it passes through the tanks. In the developing tanks these jets are so arranged that the solution is directed against the flow of the film. This high turbulence provides a uniform development free from streaks usually associated with high-speed machine work.

" During operation the solutions are continually replenished. The amount of replenisher is determined by constant pH control and by sensitometry. Sensitometric tests are put through the developing machine every 30 minutes. These strips are checked for speed, colour, and fog. A pictorial check is also made, and in this test short pieces of film, representing three different exposures of a predetermined set-up, are developed together at 30-minute intervals. The pictorials consist of a colour chart and a grey scale. One series is given normal exposure, one series is exposed one stop less (this represents underexposure), and another series of exposures represents one stop more than normal, which is overexposure. A constant check is made on the grey scale for tone and the colour patches are checked for general colour characteristics. From these tests it is possible to control the characteristics of the various solutions so that the quality output from day to day is uniform.

"In conclusion, it can be said that Ansco Color motion picture film should not be developed by hand processes. Only a developing machine will give consistently uniform quality. Machine processing is the most satisfactory method of handling the film. Good turbulence of the solutions is necessary to ensure clear, brilliant, sharp colour images. No attempt should be made to operate a continuous colour film developing process without adequate control facilities, for to do so will result only in failure. The control procedures necessary with machine process-

ing of Ansco Color Film are not difficult to use. However, to interpret the result it is obvious that a thorough knowledge of each step of the process is required."

Remarks

Contrast cannot be modified by increase or decrease of development time because the layers are developed to correct balance only at a fixed lapse of time. One or other layer would predominate if the film were developed for a different time from that recommended.

Fluorescent tubes are unsatisfactory for second exposure not only because of low intensity but owing to differential exposure due to line radiation.

It is practicable to dry the film after the first development, but very complete washing is essential.

Four solutions are circulated—1st Developer, Colour Developer, Bleach, Hypo. All solutions are continuously replenished.

Rubber squeegees are provided between each tank.

Each developing tank has horizontal and vertical pressure jets moving against the direction of film travel.

Over- and under-exposure of Ansco Color Film can be compensated for by altering the time of the first development only. If the errors to be

DEFECTS IN ANSCO COLOR FILM, AND REMEDIES

<i>Defect.</i>	<i>Possible Causes.</i>	<i>Remedy.</i>
Overall lack of density ..	Overdevelopment in first developer	None
	Exhausted stop bath	None
	Insufficient second exposure	None
	Insufficient colour development	None
Excessive density with overall "muddy" appearance	Insufficient first development	None
Excessive density with exaggerated colour and contrast	Overdevelopment in colour developer	None
Brownish streaks or spots ..	Incomplete bleaching	Rebleach, fix, and wash
Greyness or dull colours with normal overall density	Incomplete bleaching	Rebleach, fix, and wash
Overall pink stain	Insufficient wash between hardening and bleaching	None
General greenish cast	Exposure of film to sulphur dioxide fumes while drying	Rebleach (3 minutes), fix, and wash
General milky appearance ..	Insufficient fixing	Refix and wash

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corrected are two-thirds of a stop or less, the colour balance of the transparency is said not to be seriously disturbed by this procedure. The following development times are recommended.

For over-exposures of	$\frac{2}{3}$	stop,	9 $\frac{1}{2}$	minutes
"	"	"	$\frac{1}{3}$	" 10 $\frac{3}{4}$ "
"	"	"	1-1 $\frac{1}{2}$	" 8 $\frac{1}{4}$ "
" under-exposures	$\frac{1}{3}$	"	"	" 13 $\frac{1}{2}$ "
"	"	"	$\frac{2}{3}$	" 15 "
"	"	"	1	" 17 "

If exposure errors as large as about one stop have been made, the colour balance will be seriously affected.

AnSCO Color Film, 16-mm. Reversible

Types.—16-mm. Reversible. Daylight type and Tungsten type. (100 feet daylight loading spools.)

Classification.—Integral tripack three-colour Subtractive. Incorporated non-diffusing dye-couplers.

Illumination.—Tungsten type balanced for 3,200° K. lamps. (G.E. 500 watt PS. 25, or Photoflood lamps.)

Filters.—U.V. 15, 16 and 17, for absorption of excessive ultra-violet radiation at seaside, at high altitudes, or to reduce haze.

AnSCO Color Conversion Filter 10, to transform daylight to tungsten, for use of daylight type indoors. Requires 4 times exposure of Tungsten type (viz., 2 full stops).

AnSCO Color Conversion Filter 11, to transform tungsten to daylight, for use of tungsten type in daylight. Requires a half stop over that needed for daylight type.

DAYLIGHT EXPOSURE GUIDE

Exposures in the table below are suggested for use in the Temperate Zone from two hours after sunrise until two hours before sunset. In winter use a one-stop larger opening than that given in the tables, unless there is snow on the ground. With exceptionally brilliant light, such as snow scenes, or at high altitudes, the exposures given may be halved. The exposures given are for average subjects. Dark subjects require $\frac{1}{2}$ -stop greater exposure, while light subjects require $\frac{1}{2}$ -stop less exposure.

SUBTRACTIVE PROCESSES

NORMAL SHUTTER SPEED OF 16 FRAMES PER SECOND

	<i>Front-Lighted.</i>	<i>Side-Lighted.</i>	<i>Back-Lighted or Open Shade.</i>
Bright sunlight	<i>f/8</i>	<i>f/5.6</i>	<i>f/4</i>
Hazy sunlight, soft shadows	<i>f/5.6</i>	—	—
Sun overcast, bright day, no shadows	<i>f/4</i>	—	—
Sun overcast, dull day	<i>f/2.8</i>	—	—

EXPOSURE GUIDE FOR TUNGSTEN TYPE WITH 3,200° K. LAMPS OR NO. 2 PHOTOFLOOD

This table is based on exposures for average subjects in light-coloured surroundings. A dark-coloured subject will require a $\frac{1}{2}$ -stop or greater increase in diaphragm opening, whereas a light-coloured subject will require about $\frac{1}{2}$ -stop smaller diaphragm opening. Because of the difference in reflectors, the table is given only as a guide. In order to utilize the full output of light from the lamp, a reflector of good quality must be used.

500-WATT A-25 3,200° K. MAZDA LAMPS (IN REFLECTORS)

For Average Subjects in Light-Coloured Rooms. Normal Shutter Speed of 16 Frames per Second.

	<i>Lamp-to-Subject Distance in Feet.</i>				
	<i>4 ft.</i>	<i>6 ft.</i>	<i>8 ft.</i>	<i>10 ft.</i>	<i>12 ft.</i>
One lamp	<i>f/3.5</i>	<i>f/2.8</i>	<i>f/2.5</i>	<i>f/2.0</i>	<i>f/1.8</i>
Two lamps	<i>f/4.5</i>	<i>f/4.0</i>	<i>f/3.5</i>	<i>f/2.8</i>	<i>f/2.5</i>

When two lamps are used, the exposures in the table are correct only if both lamps are close to the camera, and the light from both of them must be superimposed on the subject.

The exposures given in this table apply also to the use of No. 2 Photofloods in place of the 500-watt 3,200° K. lamps. With Photoflood lamps, an Ansco UV-15 filter should be used over the lens.

ANSCO COLOUR FILTERS. FOR ANSCO COLOUR FILM

Ansco colour filters are available in two grades (Lens and Printing) to meet the requirements of two essentially different needs, for camera lenses and for laboratory printing. These filters are for use with Ansco Color Film where it is necessary to change the effective colour quality of the light by which the colour materials are exposed.

Both are supplied in the form of gelatine foils only and are made to meet exact specifications as to spectral absorption. The only difference between the two grades is in the optical quality of the filters and there is no difference in their spectral absorption characteristics. For example, striations and minor imperfections which have no effect when the filter is used over a light source may exist in the "Printing" grade filters. Because they would interfere with the quality of the image, such minor physical imperfections are not present in lens filters.

AnSCO colour filters can conveniently be classified into three groups, as follows:—1. The ultra-violet series; 2. The conversion series; 3. The colour compensating series. All of these are supplied as "Lens" filters, while only the colour compensating series and the UV-16P can be obtained in the form of "Printing" filters. The foils are edgemarked either "Lens" or "Printing," in addition to the series and number.

1. *The Ultra-violet Absorbing Filters*, as the name implies, absorb in the ultra-violet and slightly in the blue region of the spectrum. While the primary purpose of such filters is for haze correction with AnSCO Color Film, Daylight Type, in photographing distant landscapes and seascapes, and in making pictures at high altitudes, the fact that they absorb at the blue end of the spectrum makes them also useful where minor changes in colour balance are needed.

There are three filters in this series designated in order of increasing absorption as the UV-15, UV-16 and UV-17. The specific uses for each are outlined in the table.

2. *The Conversion Filters* are for exposing AnSCO Color Film when the light source differs from that for which the film was manufactured. For example, daylight contains a higher proportion of blue than does 3,200° K. tungsten illumination and therefore Tungsten Type AnSCO Color Film exposed outdoors in sunlight has a bluish appearance. However, by using a conversion filter, it is possible to absorb the excess blue light so that sunlight becomes approximately equivalent photographically to 3,200° K. illumination and in this way AnSCO Color Film, Tungsten Type, can be successfully exposed by sunlight.

In an analogous way, a conversion filter can be used to alter the balance of 3,200° K. illumination so that it approximates the effect of sunlight.

3. *The Colour Compensating Series* of filters is intended to be used for minor alterations in colour balance. For example, in photomicrography with AnSCO Color Film, the standard microscope light source may not yield transparencies of the desired colour balance. Under these circumstances, colour compensating filters can be inserted in the optical system to adjust the colour quality of the light source so that a balance is obtained.

SUBTRACTIVE PROCESSES

The chief applications of colour compensating filters are in making colour prints on Ansco Color Film, Types 732 and 132. Their use in this way is discussed in the table which follows.

ULTRA-VIOLET SERIES ANSCO COLOR FILTER FOIL

Use.

UV-15	1. Slight haze correction. 2. When exposing Tungsten Type Ansco Color Film by photoflood light.
UV-16	1. Normal haze correction. 2. When exposing Tungsten Type Ansco Color Film by photoflash light. 3. In optical system in addition to recommended filters when exposing Ansco Color Film Types 732 or 132. (Note: UV-16P filter foil replaces the UV-18 filter previously recommended.)
UV-17	1. For greater haze correction than is provided by the UV-16 filters.

CONVERSION SERIES ANSCO COLOR FILTER FOIL

Use.

No. 10	1. When exposing Daylight type Ansco Color Film by 3,200° K. illumination. The exposure should be four times that which Tungsten Type Ansco Color Film would require under identical conditions.
No. 11	1. When exposing Tungsten Type Ansco Color Film in daylight. The exposure should be 1.5 times that which Daylight Type Ansco Color Film would require under identical conditions.

COLOUR COMPENSATING SERIES ANSCO COLOR FILTER FOIL

Use.

Yellow	These 10 filters are primarily for use when printing release prints on Type 732 or making duplicates on Type 132. The filters are used to alter the colour quality of the light source used on the 35-mm. printing machine, principally for colour grading.
23	
24	
25	When a -3 filter (23, 33, 43) is added to the light system, about a 1/6 lens stop exposure increase is necessary. The 24, 34 and 44 filters are approximately twice as dense as the 23, 33 and 43 filters. When any one of the former is added to the light system, about 1/3 lens stop exposure increase is necessary.
Magenta	
33	
34	
35	The 25, 35 and 45 filters are approximately twice as dense as the 24, 34 and 44 filters. The addition of -5 filters to the light system necessitates about a 2/3 lens stop exposure increase. The magenta 36 filter is approximately twice as dense as the 35 filter and an exposure increase of 1 1/3 lens stops is necessary when it is added to the light system.
36	
Cyan	
43	
44	For the above it is apparent that when a -3 filter in combination with a -4 filter is added to the light system about a 1/2 lens stop exposure increase is necessary; likewise, when a -4 filter in combination with a -5 filter is added, about 1 lens stop increase in exposure is necessary.
45	

PARTIAL PROCESSING OF ANSCO COLOR FILM

Inasmuch as Ansco Color Film, during processing, must be exposed to white light after the first development and the stop bath, it is evident that if processing cannot be completed at the time, it may be interrupted at this stage and finished later. If this is to be done, the film should be washed for at least 10 minutes in cold water and dried.

Advantage may be taken of this fact when working far from the studio or under highly unfavourable conditions. In its semi-processed state, the film is less susceptible to deterioration and damage than unprocessed film. It may be exposed to ordinary room light without harm. In addition, it can be stored for appreciable periods without change in colour quality or degree of exposure. On the other hand, exposed but unprocessed colour film may show noticeable loss of the latent image as well as marked shifts in colour balance on prolonged storage.

Explorers, magazine correspondents, and others who are unable to carry complete processing equipment and supplies, may arrange to do only the first development and the stop bath en route, following which the films are returned to headquarters for completion, with the knowledge that the films will not deteriorate during shipment through tropical zones. In addition, since the partially processed films have a visible negative image, they may be examined by censors, customs officials, etc., before completion.

The remaining steps either may be carried out by the photographer himself or the partially processed films may be returned to the Ansco Color Laboratory, Ansco, Binghamton, N.Y., for completion.

WARNING: There is no satisfactory way of distinguishing partially processed films from unprocessed films in total darkness. Any films received at Binghamton will be processed through the entire procedure unless the package is clearly marked to the effect that the films have been given first development. Films which have been given first development and are subsequently processed as ordinary exposed Ansco Color Film are irretrievably spoiled. For this reason, in returning semi-processed films to Binghamton for processing be sure to mark the package clearly: "First Developed—Open in White Light," or if there is insufficient space on the package, simply mark it "Department K."

In carrying Ansco Color Film through only the first three steps of processing, the same procedure should be followed as though the processing were to be completed, with the exception that the rinse following the stop bath is extended to a wash of roughly 10 minutes' duration. The temperature of the first developer should be carefully controlled and kept at 68° F. (20° C.), while the stop bath may be used at between 60° and 70° F. (16° to 21° C.). Agitation must be in accordance with instructions—differing amounts of agitation in the first and second developers may produce marked variations in colour, density, and equality of finished transparencies. The film can be exposed to

ordinary artificial light at the completion of the stop-bath step and needs only to be protected from heat and mechanical damage from this point onward.

One danger involved is that of excessive swelling, reticulation, or frilling of the emulsion during the wash. Water which is too soft or too warm will give trouble, so that wherever possible hard water should be used, and in any case, the temperature should be kept below 70° F.

In tropical climates, where the running water supply is generally warm, it is desirable to substitute washing in several changes of cooled water for the 10-minute wash in running water. Ten 1-minute rinses with constant agitation, using fresh water for each rinse, is ample.

Following the wash, the film should be dried in the normal way, avoiding the application of excessive heat. After drying and during storage it should be protected against extremes of heat and humidity, as well as against mechanical damage and strong light such as daylight and direct sunlight.

References

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- HARSH, H. C., and FRIEDMAN, J. S., "One-Strip Color-Separation Film," *Journ. Soc. Mot. Pic. Eng.*, **50** (Jan. 1948), p. 8.
- RAY, R. H., "Use of 35-mm. Ansco Color Film for 16-mm. Color Release Prints," *Journ. Soc. Mot. Pic. Eng.*, **53** (Aug. 1949), pp. 143-148.

The Bertrand Process (Paris)

Camera.—Kodachrome 16-mm. is used for the original record.

Printing.—35-mm. separation negatives made by optical enlargement. Three successive printings are said to be made on one surface which has been successively sensitized with diazo direct printing-out dyes.

Projection.—Normal.

Remarks.—No record of prints having been exhibited publicly.

The Brewster Process. (No longer worked)
(U.S.P. 1,752,477, 1930.)

Camera.—The late P. D. Brewster, an American inventor who was one of the first to apply the bipack system to colour cinematography, had a number of patents to his credit covering various cameras and printing machines. In E.P. 130,002 a camera is described for the production of two-colour films in which the usual arrangement is adopted of two gates at right angles to each other, and a prism cube with cemented reflecting face half-silvered, and disposed at 45° to the axis of the beam. In U.S.P. 1,752,477 the prism is replaced by a rotating mirror (Fig. 224).

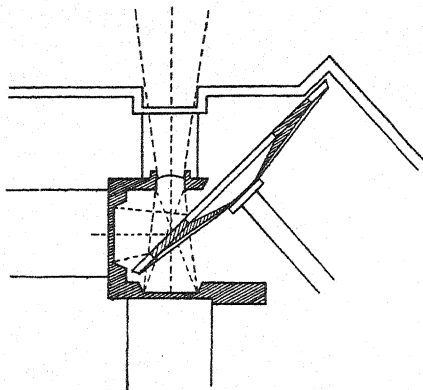


FIG. 224.—Brewster's U.S.P. 1,752,477.

The following description of Brewster's camera appeared in the *Photographic Journal* (75, August 1935, p. 455):

Brewster's suggestion was that the light should be divided up between three separate negatives, each of which should receive light from the whole of the lens. The way in which that was done was to make use of metallic mirrors, rather like propellers, disposed at right angles to each other. Dr. Spencer (who presided at the meeting of the Royal Photographic Society at which the Brewster process was demonstrated, April 12, 1935) sketched the design on the blackboard, pointing out that if one "propeller" was spun round on its axis light would be reflected from the vanes on to the film at right angles to the entering beam, and when the propeller had made one complete revolution the whole of one image would be completed. As, however, the vanes had apertures between them, light would be transmitted at the same time to the rear image. If at an angle to the first propeller a second were placed the period of revolution of which was so arranged that the two would cross each other's path when revolving without interfering with each other, as soon as one vane of the first reflector moved out of the way a vane of the second reflector could cross the path just left, and so the image was obtained with one complete revolution of the vane. It would be appreciated what a high precision job it had to be. An absolutely steady picture had to be cast on each of the three frames, which meant that the mirrors must be finely worked surfaces, finely disposed. (See Chapter V for further description.)

In adopting this type of camera Brewster attempted to avoid the defects of bipack. All three negatives should be of maximum definition. The film shown on the occasion referred to above was free from halation and had good definition of distant detail.

Printing.—Brewster employed double-coated positive film printed on one side with the red filter negative and on the other side with the green filter negative. The development of these was carried to a low gamma, and exposure was light. These two images were converted into silver iodide and dyed with basic dyes—a process originally invented by A. Traube (D.R.P. 187,289, 1905). The side printed with the red filter negative was dye-toned subtractive primary cyan; the side printed with the green filter negative was dye-toned subtractive primary magenta. The remaining yellow component was printed on top of the dye-toned image by imbibition from a relief matrix film made in the customary manner by developing with a tanning developer such as pyro or pyro and adurol. The unhardened gelatine was dissolved away with hot water after development. Such a method was elaborate and must have been somewhat difficult to control both as to registration and colour balance.

The following description appeared in 1935:

The red and green negative records are printed on to two sides of a double-coated positive film. The images are bleached out to invisible silver iodide images, and are toned with basic dyes to pink and blue. The pink side is then *coated with another emulsion*, which is exposed to the blue negative record and correspondingly tinted by a new process which is not being divulged until further patents have been granted. Basic dyes are said to give an advantage over the acid dyes used by Technicolor.

Remarks.—This printing system would not prove very practicable for commercial work, and it is difficult to see how such an elaborate processing sequence could have competed with Technicolor.

CERTAIN BREWSTER PATENTS

E.P. 2,463	..	..	..	..	Brewster, P. D.	1913
E.P. 2,465	..	..	..	..	..	1913
U.S.P. 1,145,968	..	..	..	..	..	1913
E.P. 3,435	..	..	..	..	..	1914
E.P. 1,073	..	..	..	..	..	1915
E.P. 100,082	..	..	..	..	..	1915
U.S.P. 1,191,941	..	..	..	..	..	1916
E.P. 130,002	..	..	..	..	..	1918
U.S.P. 1,308,538	..	..	..	..	..	1918
U.S.P. 1,355,938	..	..	..	..	..	1918
U.S.P. 1,359,025	..	..	..	..	..	1918
U.S.P. 1,410,884	..	..	..	..	..	1922
U.S.P. 1,508,916	..	..	..	..	..	1925
U.S.P. 1,537,524	..	..	..	..	..	1925
U.S.P. 1,563,959	..	..	..	..	..	1925
U.S.P. 1,752,477	..	..	..	..	..	1930

COLOUR CINEMATOGRAPHY

U.S.P. 1,214,940	..	..	..	Millar, Hoyt, assigned to Brewster Corp.
E.P. 450,673	..	..	..	Brewster, P. D. 1934

See Brewster, P. D., "Three-Color Subtractive Cinematography," *Journ. Soc. Mot. Pic. Eng.*, 16, No. 1 (Jan. 1931), p. 49.

Chimicolor

French process developed by the *Syndicat de la Cinématographe des Couleurs*, formed in 1931. (F.P. 756,344, etc.)

Classification.—Three-colour subtractive process.

Camera.—Beam-splitter, or successive frame R.G.B. negative on one film or 35-mm. separation negatives optically extracted from 16-mm. reversal colour film such as Kodachrome or Agfacolor. The beam-splitter camera is shown in Figs. 226 and 227.

Printing.—Normal machines equipped with register pins. There is a special Debie printer made for double-coated stock.

Processing.—Developed to low gamma and density. Double-coated film dye-toned by mordanting. One side re-coated with gelatine. Sensitized with bichromate and exposed to a *positive*. Exposed and therefore insolubilized gelatine rejects dye. This is strictly in accordance with the technique of the *PINATYPE* process of Leon Didier (F.P. 337,054—1903; U.S.P. 885,453—1908; E.P. 7,557—1905). The third printing is hence produced by differential absorption of a dye applied to the re-coated surface. A protective varnish is applied to the finished product.

General Remarks

There is considerable interest in France in this process, the technique of which is based upon a combination of operations in no respect novel in the history of the art. What has been accomplished is largely the result of a determined effort to make practicable operations which are uncontrollable without specialized equipment and apparatus. Work dates back to 1931, but in 1940 the *Syndicat de la Cinématographie des Couleurs* wanted to re-open its research laboratories in Paris but they did not get authorization from the Germans, who ordered them to close the laboratories. Nevertheless, the *Comité de l'Industrie Cinématographique* and M. Ploquin persisted in supporting their research work and helped them as much as possible. But work was paralysed for lack of raw materials, but in spite of all the difficulties they succeeded in completing a well-equipped research laboratory, which was very nearly discovered at the time of the Normandy invasion. Immense difficulties were experienced with finance for these efforts since Paris appears to have had plenty of charlatans trying to raise money for all sorts of colour processes. The process seems to owe a lot to M. Thiengard whose enthusiasm carried the work on during the occupation, and technically

to R. Valette who was a pupil of Leon Didier, the inventor of the Pinatype process. Didier was an associate of the great Ducos du Hauron, so that that process can boast a sound ancestry.

A prototype beam-splitter of the Technicolor type has been completed. So far no work has appeared except animated cartoons photographed by the familiar successive R.G.B. frame method on one film (Fig. 226).

Low-density silver prints are made on opposite sides of normal double-coated positive from the red and green separation negatives. Mordanting follows. The mordant has not been divulged. The statement has merely been made in published descriptions that sensitometric control is of vital importance and this is quite understandable. Valette has provided dyes having particularly suitable absorption spectra and fastness to light. The nature of these is not revealed but they are presumably variants of existing basic dyes. The mordanted film is dyed on a special machine which applies the dyes to the respective surfaces in succession, making use of capillarity principles (presumably by flotation). The sound track is a cyan dye image.

To obtain the third yellow print Chimicolor is original in making use of the principles of *Pinatype*. The film is accordingly given on one side (probably the magenta-toned side) a coating of gelatine only. This is sensitized with bichromate—probably a suitable mixture of potassium and ammonium bichromate. The printing is carried out with a *positive* made from the blue filter negative upon the sensitized gelatine employing a very powerful source of ultra-violet such as a high-pressure compact source mercury discharge lamp (Fig. 228). Needless to say the sensitization operation will require extremely accurate control of humidity and temperature. An interesting point is that the dyes used for the first dye-toning operation must have unusually high fastness to light for basic dyes to withstand the intense radiation of ultra-violet to which they must be subjected in the exposure of the bichromated layer.

An interesting review of the process was given in *La Cinématographie Française*, No. 1176 (Oct. 1946), by A. P. Richard, from which the following schematic operational sequence is derived:

1. A. Direct photography { 3 primary records on the same film.
 3 primary records on 3 films.
 { from additive films such as
 Dufaycolor, from multilayer
 subtractive films such as
 Kodachrome, Agfacolor, Ge-
 vacolor, etc.
- B. Indirect. Separation of 3 records
2. Sensitometric characteristics are determined.
3. Printing No. 1.—Printing from 2 primary record negatives on double-coated film.

COLOUR CINEMATOGRAPHY

4. Development → Washing → Mordanting → Washing →
Dyeing → Washing → Drying → Control.
5. Sensitizing of one side of the double-coated film → Drying.
6. Printing No. 2.—3rd image (Fig. 229).
7. Dyeing—3rd image → Washing → Drying → Control (Fig.
230).
8. Final Protective varnishing.

British Tricolour

(The process was taken over from British Tricolour Processes Ltd. by Dufay-Chromex Ltd. in 1948. See "Dufaychrome.")

Dufaychrome

(Made by Dufay-Chromex Ltd., London, England.)

Classification.—Three-colour subtractive printing process.

Two- or three-colour print on non-sensitized emulsions containing substantive colour couplers, involving resensitizing steps, separate printing, and single processing.

Camera.—

(a) *Beam-Splitter* (Fig. 232). Prism beam-splitter embodying a prism block consisting of two 45° prisms cemented together to form a cube, one of the 45° faces being coated with a partially reflecting surface of gold. The prism diverts part of the beam originating from the lens to a film gate at 90° to the lens axis, the balance of the beam passing through the prism to a gate in the normal position.¹

(b) *Three-strip Negative Arrangement*. Bi-pack records the diverted (*viz.*, reflected) beam. (Blue and red records.) Single film records the direct beam. (Green record.) The bi-pack consists of a non-sensitized, hence blue-recording, front film, the emulsion surface of which is coated with a red filter excluding green and blue light from the rear film which is coated with a highly red sensitive emulsion.

The single film bears a green sensitive emulsion which is exposed behind a minus blue (yellow) filter. This combination of films is known as "Three-Strip," and is supplied by Eastman Kodak to the special requirements of Dufaychrome.

(c) *Successive Frame Negative*. Alternatively to the three-strip system, for static subject matter, separation negatives are recorded on a single film as successive sets in the order blue, red, green. A disc carrying the filters rotates in gear with the camera drive, each exposure being covered by a rotation of 120°. Eastman Background X is generally used. Exposure is balanced to yield a density of 1.50 for the "white step" of a standard chart. The "white step" density should not vary by more than plus or minus 0.10 between the three colour records. To achieve this the luminance of the exposing light is adjusted or the

¹ See *Journ. Soc. Mot. Pic. Eng.*, 50 (June 1948), pp. 543-553; also *Brit. Journ. Phot.*, 66 (May 1949), pp. 218-219.

exposure of one or other of the colour records reduced. Generally it is the red which must be reduced by some 75% and the green by some 25-30%. This is accomplished either with neutral filters of density 0.60 and 0.15 for the red and green filters respectively, or the disc sectors can be masked proportionately. It is preferable to mask equally at either end of a sector rather than to mask at one end only. The filters used are Chromex 608 (Blue); 609 (Green); 657 (Red).

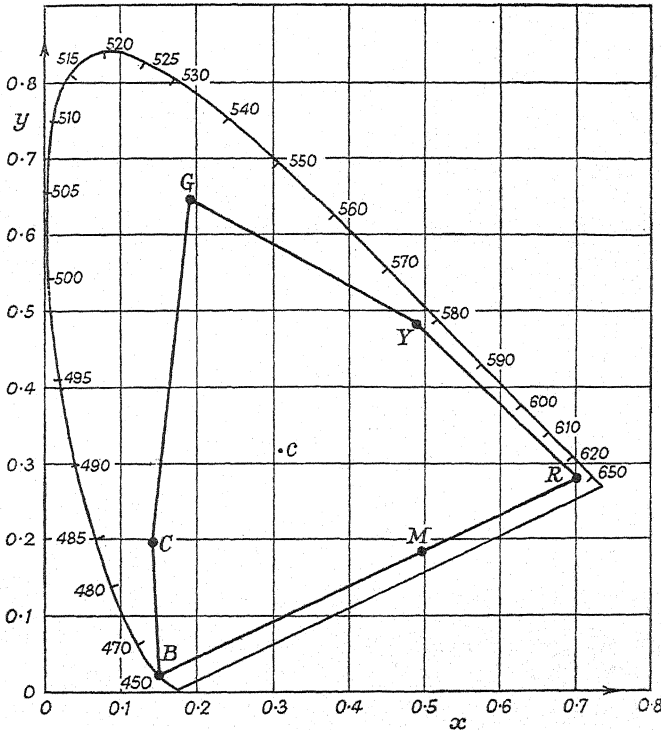


FIG. 233.—Dufaychrome primaries and chromaticities of subtractive admixture.

(d) “*Monopack*.” It is feasible to use separation negatives derived from any reversal original colour film such as Kodachrome, Ansco Color, Agfacolor, Gevacolor.

Printing.—The blue-record negative of a separation set is printed on to a positive (non-colour-sensitized) emulsion layer containing an immobile yellow colour former. The latent image formed by the first printing operation is not immediately developed, but, instead, the film is resensitized with positive emulsion—this time containing an immobile magenta coupler. The magenta-forming layer is printed behind the green-record negative. Neither of the two latent images so far formed is yet developed, and the film is again sensitized with a positive emulsion—

this time containing an immobile cyan coupler. When the cyan layer has been printed from the red record negative, the pack is ready for a single colour development operation and the subsequent removal of the three resulting metallic silver images (E.P. 608,507).

A sound track is added by coating the transparent track area with whatever type of positive emulsion may be required for the best sound quality. After exposure, the track is processed to a metallic silver image in a normal manner, no protection of the picture area being necessary.

Projection.—Normal.

Processing.—Identical to Agfacolor positive. (See Agfacolor.) Namely,

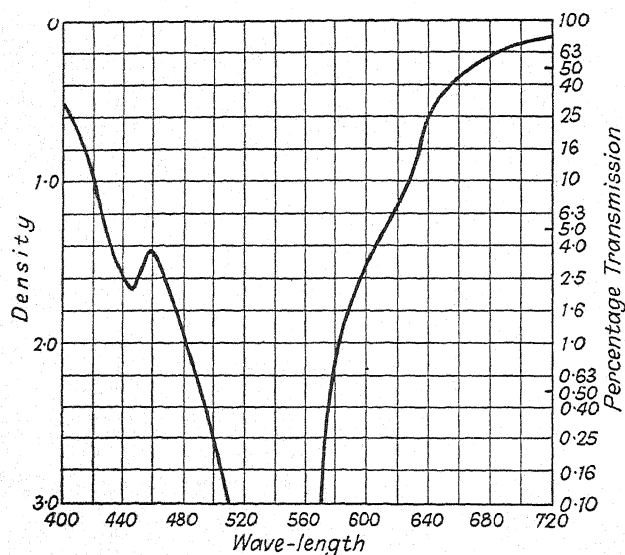


FIG. 234.—Dufaychrome Magenta. Spectral Transmission.

a developer, such as diethyl-p-phenylene diamine hydrochloride, followed by washing, hardening, bleaching for removal of silver, fixing and washing.

General Description.—This process presents a “set-up” very like Technicolor, namely, a beam-splitter camera of generally similar design: a straightforward three-colour printing job by successive printings all on one side of the film base and all surface contact printed; and a normal silver sound track. The credit for this remarkable achievement goes to Mr. Jack Coote, F.R.P.S., the well-known author of “Making Colour Prints.” For once we have a process conceived and carried through to the commercial stage by a man who before he began developing the process was master of the general subject of colour photography; whereas most processes are misshapen and generally

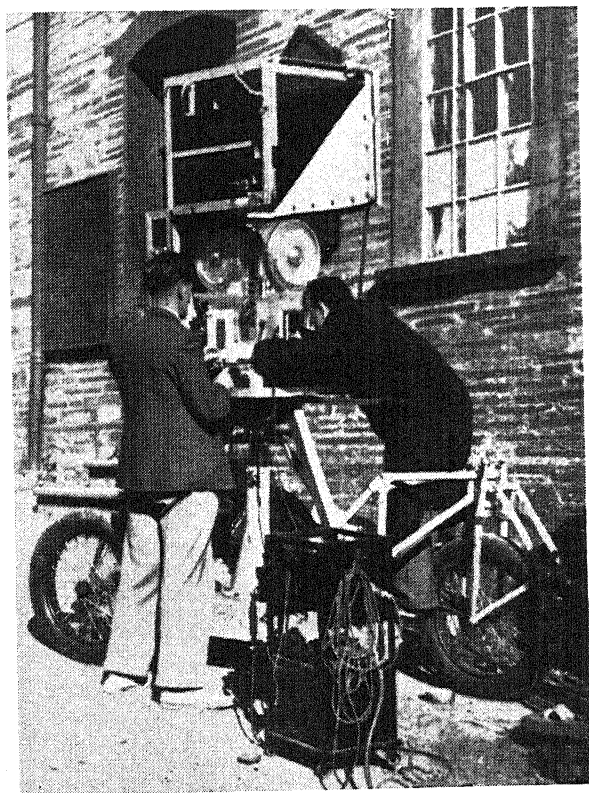


FIG. 225.—The Brewster rotating-mirror camera, 1935.

(Facing p. 416)

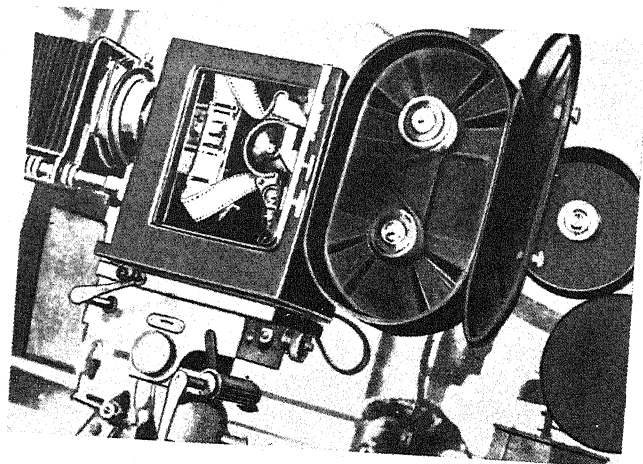


FIG. 226.—Chimicolor beam-splitter "three-strip" camera.

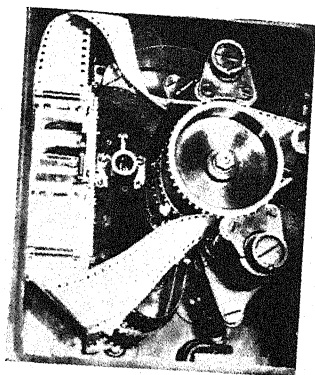


FIG. 227.—Chimicolor.
Film gate and part of action.

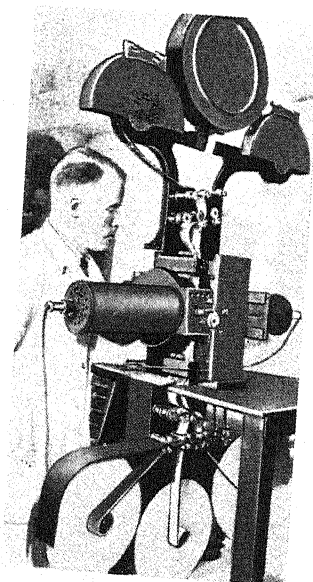


FIG. 228.—Chimicolor Printing
Machine for film coated with
bichromatized gelatine.

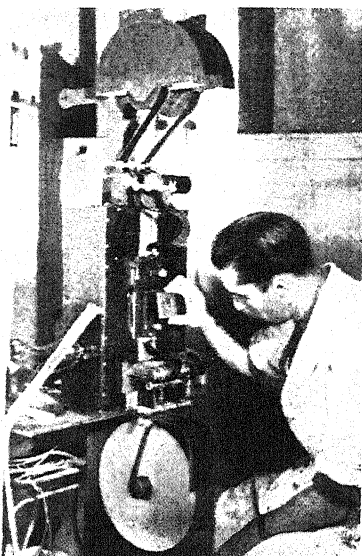


FIG. 229.—Chimicolor.
Printing the 3rd image.

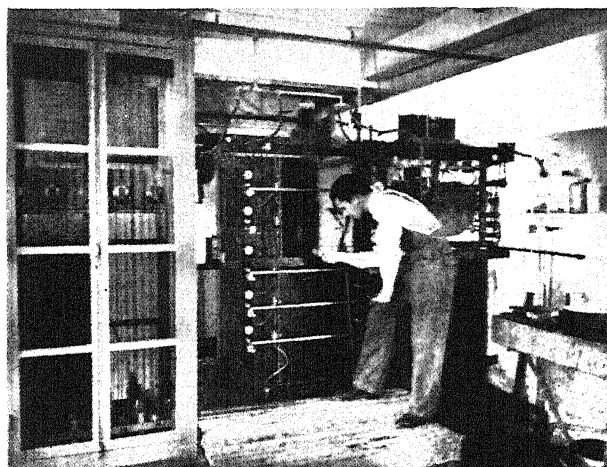


FIG. 230.—Chimicolor.
Dyeing the 3rd image.

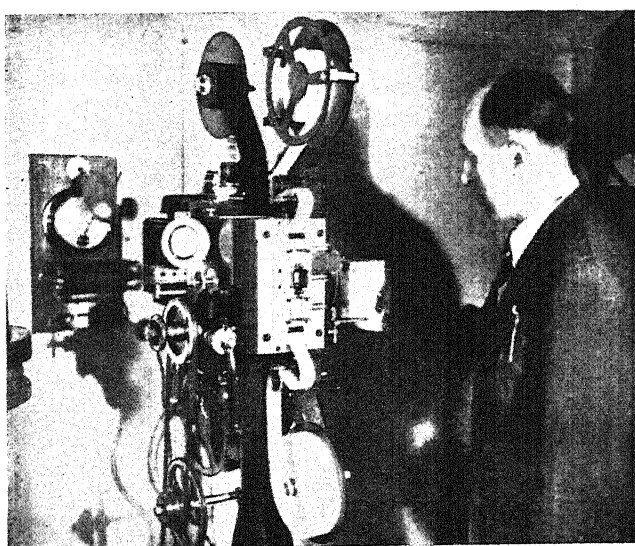


FIG. 231.—Chimicolor.
Optical printer.

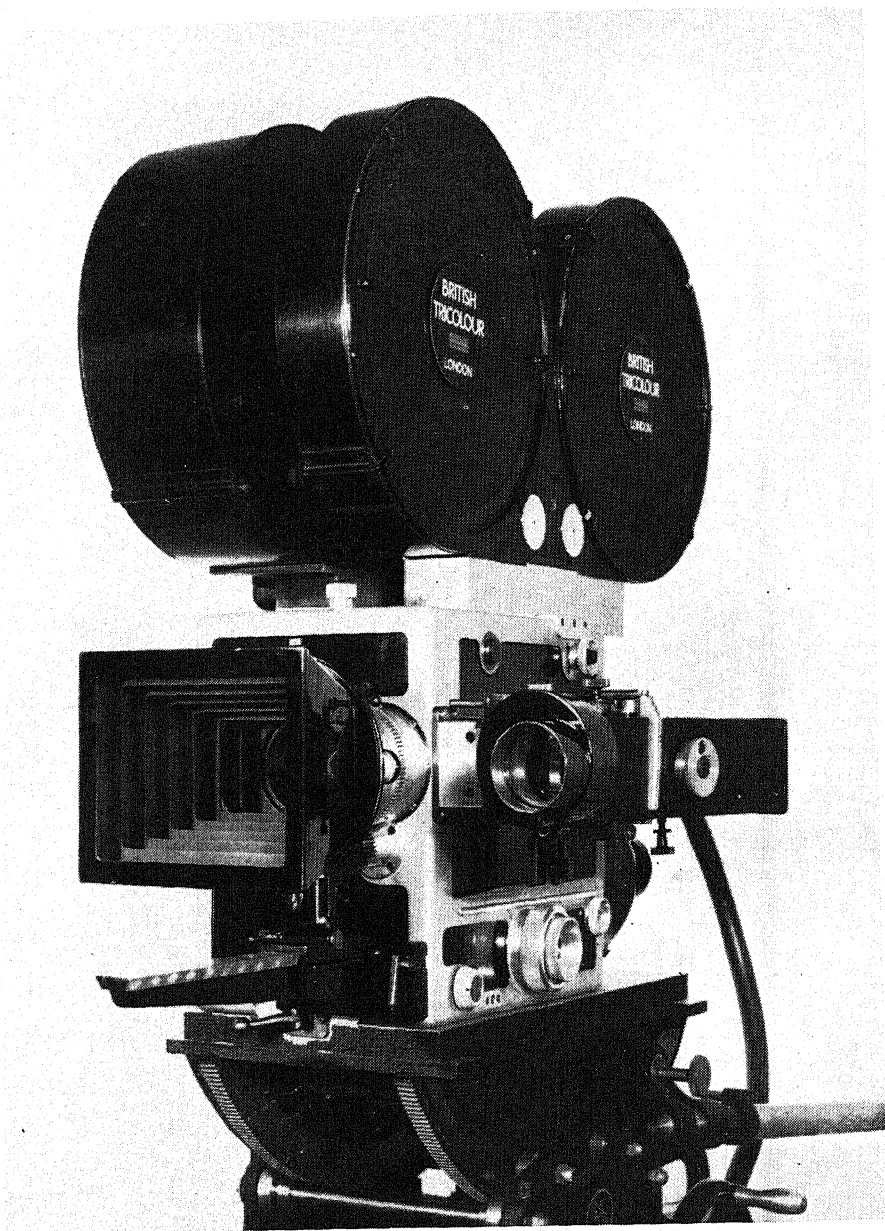


FIG. 232.—Dufaychrome Prism Three-colour Beam-Splitter for “ Three-Strip ” film.
(Formerly British Tricolour Processes.)

(Facing p. 417)

illegitimate offspring of doubtful parentage, this time we know the

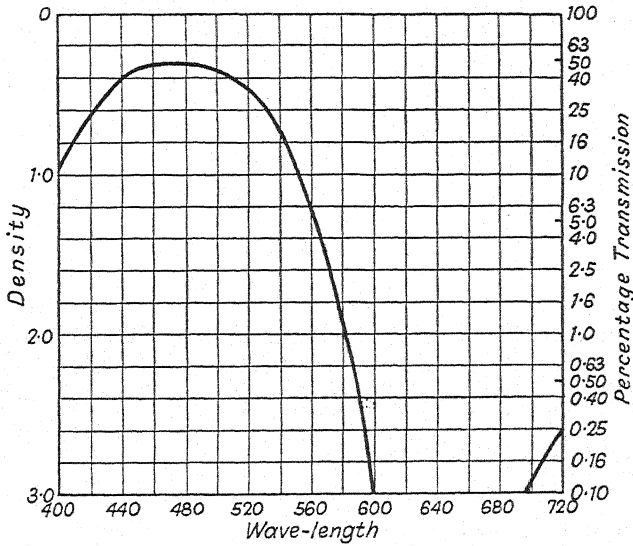


FIG. 235.—Dufaychrome Cyan. Spectral Transmission.

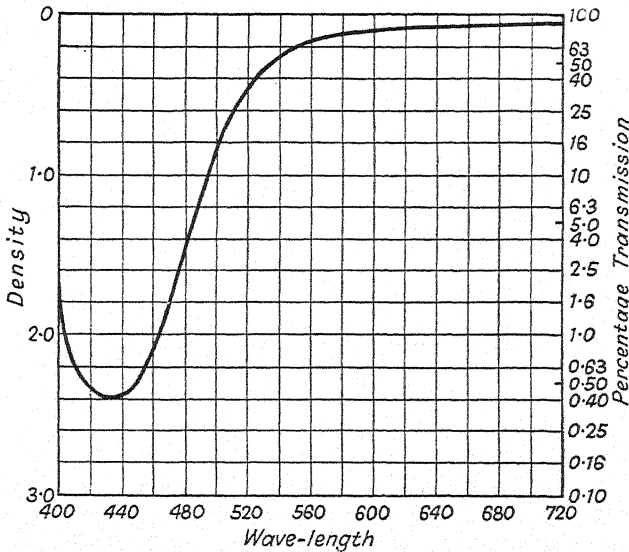


FIG. 236.—Dufaychrome Yellow. Spectral Transmission.

parent and had cause to expect furthermore the child to be gifted and exceptional. And so indeed it turned out to be.

Coote always agreed with the writer entirely that the right and proper

first (recording) stage in a colour process is a good set of separation negatives. Coote has paid some attention to stripping integral tripacks, but soon found that to perfect a new product of this type would mean prolonged research, so that he decided to take the plunge and evolve a beam-splitter. Considering that Technicolor have always done their best to scare others away from this field, Coote was very brave to go through the gate and challenge the fearsome creature within. In this trial of strength he has proven himself a worthy opponent and the champion must look to his laurels (Fig. 232).

At the time of writing the commercial exploitation of this process is limited to Gt. Britain, but rapid developments are bound to occur. Studio tests have proven the camera to be an efficient instrument and the printing process yields a wide chromaticity range (Fig. 233). Table 62 shows the position of the Dufaychrome subtractive primaries on the chromaticity diagram, Illuminant C. being used, and the additive primaries modulated by these. Figs. 234-6 give the spectral transmission of the Dufaychrome subtractive primaries.

TABLE 62.—DUFAYCHROME SUBTRACTIVE PRIMARIES.

<i>Colour.</i>	<i>x.</i>	<i>y.</i>	<i>T</i> %	<i>Purity</i> %	<i>Dominant</i> <i>Wavelength</i> <i>mμ.</i>
Yellow 1	·490	·485	57·0	94	578
Magenta 2	·498	·188	2·2	87	—499
Cyan 3	·143	·199	14·7	74	482
Red 4	·704	·280	1·65	96	643
Green 5	·194	·646	4·7	76	528
Blue 6	·150	·020	0·03	100	455

The Dunning Colour Process (1936)

Camera.—A beam-splitter was employed, the gates being side by side. A panchromatic negative and a bipack were exposed through graduated filters, which were adjustable in order to compensate for different lighting conditions—daylight, incandescents, or arcs. No details were published.

Printing.—Standard double-coated positive stock was used, the magenta and cyan images on one side and the yellow on the other.

Remarks.—The cyan printing negative was obtained on a single film. The bipack recorded blue and green light. The magenta and blue-green images were obtained in a single layer of the double-coated positive.

The Gasparcolor Process

(Gasparcolor Inc., Hollywood, California.)

Classification.—Three-colour subtractive process. Integral layer type emulsions incorporating complete dyes to be bleached in neighbourhood of developed silver during processing. So far available only as positive printing film requiring black-and-white intermediate positives as printers. Belongs to the category known as silver-dye-bleach processes.

Introduction.—Gasparcolor was the first 35-mm. integral layer tripack film (known also as monopack and multilayer) to be used commercially. The credit for this historically important achievement belongs to Dr. Bela Gaspar, a Hungarian by birth, now resident in the United States. Gasparcolor antedates by at least a year both Kodachrome and Agfacolor, from both of which it differs fundamentally in its classification as a dye-destruction process and not a dye-forming process.

In 1934 Gasparcolor Ltd. was formed in Great Britain, and with Gasparcolor positive film stock coated by Gevaert of Belgium a large number of very beautiful release prints were made. The laboratory technique and general technical supervision were under the control of the writer. It is important to emphasize that these were the first commercial monopack prints because this honour has been claimed elsewhere. They were furthermore the first of such prints to be processed in a standard 35-mm. automatic processing machine installed in a commercial film laboratory. Similarly, they can also claim to have been the first of such prints to carry a normal silver sound track record, whilst having a pure dye picture image.

Indeed, it seems that Gaspar's position as an outstanding pioneer deserves more recognition than it has already received. It has been entirely overlooked that in his U.S.P. 2,071,688 (*cf.* claim 15, page 3, second column, last paragraph; see also E.P. 416,566, page 6, line 36) he disclosed the first colourless, water-soluble, non-diffusing, dye-forming substance with a convention date going back to December 9, 1931, before I.G. Farben had started their work on Agfacolor.

During the Second World War Gaspar was domiciled in the U.S., cut off from the research laboratory he had organized in Brussels; this was looted by the Germans and a number of his scientific staff imprisoned or killed. Under adverse conditions he carried on his research in the U.S., where, receiving little encouragement from a motion picture industry dominated by huge monopolies, he decided to devote himself to the solution of the problem of still colour prints. An admirable material was manufactured for Government use during the war. It is probable that this still print material will shortly be generally available.

History.—K. Schinzel's "Katachromie" (*Brit. Journ. Phot.*, 52, 1905, p. 608) was almost certainly the first monopack to be fully described. A plate was to be coated with dyed emulsion layers. The top layer was to be dyed yellow and sensitive to blue light only. The middle

layer was to be dyed cyan and sensitized to red, while the magenta-dyed layer was to be placed at the lowest level and made sensitive to green. The negative after development was to be immersed in hydrogen peroxide, which, being decomposed by the developed silver, resulted in released oxygen which destroyed the dyes. After removal of the silver a positive image in full colour would remain. R. Neuhauss pointed out that it would in fact be next to impossible to prevent bleaching of the dye in the non-image areas (*Phot. Rund.*, 19, 1905, p. 239). Whether workable or not, here is the first suggestion for coloured image making by catalytic dye destruction. Christensen (U.S.P. 1,517,049 and E.P. 133,034) tried to apply the dye-discharge methods used in textile printing. But such reducing agents as hydrosulphite or stannous chloride would attack the dye in unwanted areas, and there could be no certainty that the dye would be destroyed only in the presence of finely divided silver (viz., at image points). Similarly, G. P. J. Schweitzer (E.P. 249,530) destroyed the dyes in the three layers by a bleach consisting of sodium bromate and sulphuric acid, the silver acting upon the bromic acid to release nascent oxygen, which served to destroy the dye.

Gaspar solved the problem by discovering a group of reagents which have the property of attacking the dye only in the presence of the silver. Friedman has pointed out that these, as a group, all contain labile hydrogen, which can therefore form simple or complex silver salts, a condition that appears to be a requisite for the Gaspar dye-bleach solution. Thus thiourea, thiocarbamide, guanadine, thiodiglycolic acid, etc., are all mentioned in Gaspar patents. These reagents he calls "indifferent solutions," namely indifferent to the dye save in the presence of silver, thereby eliminating the use of strong reducing or oxidizing agents which his precursors had required. Thus Gaspar has achieved the only reliable method of producing dye images in a multilayer material other than by the methods originating in the work of Fischer based upon colour development or inclusion of colour-forming substances in the emulsion, as applied in Kodachrome and Agfacolor or Ansco Color. Gaspar's method is historically more recent and is the only one permitting the use of complete dyes, among them a considerable number of textile dyes and practically all types of azo dyes. Thus Gaspar has the undoubted advantage of obtaining colours of high saturation and great fastness to light, in which properties the other processes are deficient. Gaspar claims the inestimable advantage that since the dye destruction is proportionate to the original silver image, his colour image is a straight-line reproduction of the silver image. More recently Gaspar has discovered means of speeding up the action of the bleaching reagents by a considerable range of catalysts.

Gaspar's patents cover a great many combinations whereby the layers may in part or wholly be uncoloured until the processing stage is reached. The colourless layers can be coloured diffusely as a stage of processing

and thereafter dye images produced by local dye destruction. The most promising of these methods proposes the use of azo dye-forming substances, or azo couplers. These compounds would permit the use of normal high-speed negative emulsions, which can be developed by the usual technique to a fine-grain, low-gamma image, so that high speed and excellent latitude can be obtained. After development these silver images are transformed by straightforward processing steps into transparent dye images.

In addition to the azo dye images, which have proved the most practicable, Gaspar has developed a number of other alternatives. He first conceived the principle, which has been developed by other inventors, of colouring all three layers in a multilayer material with one dye which was decolorized and subsequently processed to another colour in any given layer. U.S.P. 1,956,122 was granted in 1934, and E.P. 369,660 was published in March 1932. The principle therein described was put to good use in the earliest form of Kodachrome. Also methods have been described by Gaspar for the use of vat dyes in the form of colourless and very fast reduction compounds, the so-called leuco-esters. These patents date back to 1930. Little was done to develop this field owing to control of these compounds by the German dye trust (namely, I.G. Farben).

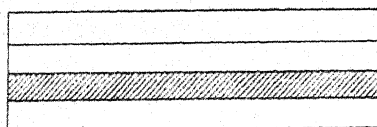
Camera.—It is essential to employ a camera equipped with pilot pin registration. Colour separation negatives obtained with the aid of beam-splitting optical systems can be used, as well as colour separations made from monopacks (such as Kodachrome or Ansco Color). For cartoons it is usual to record the separations successively on one film, employing a title or trick camera equipped with a rotating disc carrying the red, green, and blue filters. From a negative so made every third frame is selected by an optical printer when making the positive intermediates from which the Gaspar positive is printed.

Projection.—Projection is normal, no change being required.

Printing.—Standard nitrate base for motion picture film is coated with three layers of emulsion containing dyes which can be bleached by the action of a suitable reagent in proportion to the quantity of developed silver (Fig. 237).

Whereas all the layers may be coated in superposition on to the same side of the support, Gasparcolor film is double-coated, two layers on one side, magenta on top and yellow beneath, the third cyan layer being on the other side. Each layer can be printed independently of the other in the following manner: the magenta layer is blue sensitive only, and it is printed with blue filtered light; the underlying yellow layer is sensitized to red light, but as it is dyed yellow little or no blue light can penetrate this emulsion, so that when the upper magenta layer is printed with blue light the underlying layer is unaffected thereby. Next, the yellow layer is printed with red light, the

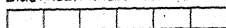
Pink emulsion
Yellow emulsion
Celluloid base
Blue emulsion



Sensitive to Blue light
Sensitive to Red light
Sensitive to Blue light

Section of Gasparcolor Film

Blue. Red. White. Yellow. Green. Black.

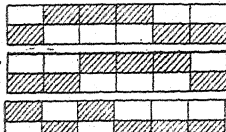


The Original Subject

Red Filter Negative
" " Positive

Green Filter Negative
" " Positive

Blue Filter Negative
" " Positive

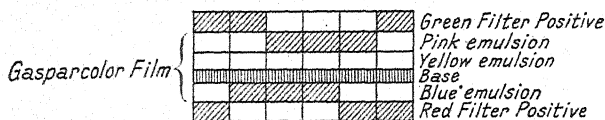


To print Blue emulsion

Negatives taken through trichromatic filters and normal Positives, contact printed therefrom.

Light Source (First printing with Blue light upon Pink layer)

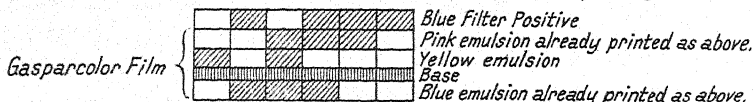
Blue Filter



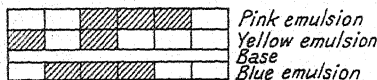
Blue Filter (Second printing with Blue light upon Blue layer)

Light Source

Red Filter (Third printing with Red light upon Yellow layer)

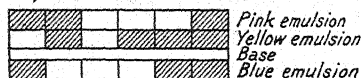


Developed Gasparcolor Film after completion of three printings. Dark areas represent developed silver.



After reversal and complete removal of silver. Dark areas represent clear coloured gelatine.

Gasparcolor Film ready for Projection.



Which represents by transmitted light



FIG. 237.—The Gasparcolor process.

SUBTRACTIVE PROCESSES

upper layer recording nothing. It should be noted that the upper layer being magenta it will be transparent to the red light used for printing the yellow layer, while at the same time no green light can penetrate it, its colour being minus green (magenta), which is opaque to green light.

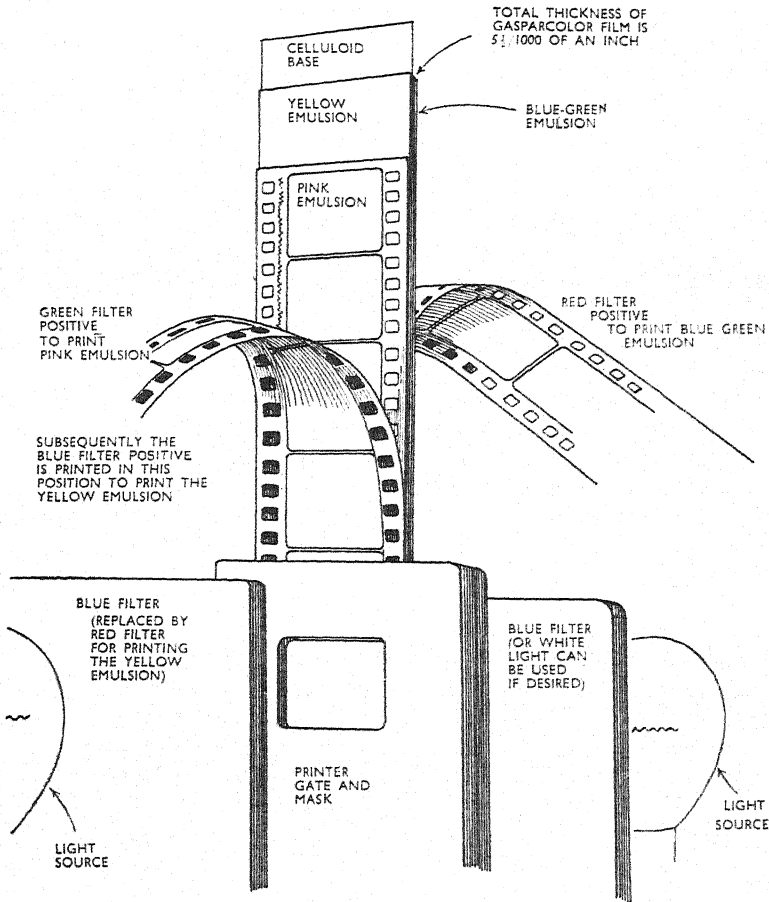


FIG. 238.—Simultaneous printing of both sides of Gasparcolor film.

On the other side of the film the cyan layer is sensitive to blue light only, and being dyed blue it will be transparent to these rays, whereas the blue light will not affect the yellow layer lying on the other side of the film, and, as we have remarked before, the yellow layer excludes blue light. Thus it will be evident that the three layers can be independently printed with suitable three-colour negatives.

The printing operation is carried out on normal contact step-by-step

COLOUR CINEMATOGRAPHY

printing machines, the only difference between colour printing and black-and-white printing being that the film is printed three times with appropriate colour filters between the light-source and the film (Fig. 238). The speed of the respective emulsion layers is comparable to ordinary motion picture positive film. Printing cannot be carried out in red light, a fairly light green safe light being employed.

As the ensuing processing sequence terminates in an image the reverse of the exposed and developed silver, it is necessary to print with positives. The first stage in the process is to make a set of three master positives, with which, of course, any number of Gasparcolor prints can then be made. This stage of the process permits a very accurate control of contrast should some modification of the character of the original negatives be desirable.

The printing complete, the film is now passed through the following baths: it is developed, washed, fixed, washed, subjected to local dye destruction by the action of acid thiourea (in this bath the dyes are destroyed in proportion to the presence of developed silver), washed, bleached (in this bath the metallic silver is transformed into silver chloride in preparation for the total removal of the silver). At this point the sound track (now silver chloride) is rapidly redeveloped, the developer being applied by a narrow wheel in such a manner that the sound track is alone redeveloped; then the film enters hypo, which removes all remaining traces of silver halide; finally, it is washed and dried. If the sound track is not redeveloped a sound record will be obtained which is a pure dye image.¹

GASPARCOLOR TIME-TABLE FOR PROCESSING

<i>Operation.</i>	<i>Minutes.</i>	<i>Totals.</i>
Wash	2	2
Development	9	11
Wash	2	13
Fix	9	22
Dye Bleach	11	33
Wash	9	42
Bleach	5½	47½
Wash	2	49½
Sound Redeveloper	3	51½
Fix	6	57½
Wash	7	64½

¹ This would not be an objection now that the R.C.A. phototube 1P-37 is available (caesium-antimony alloy cathode).

Gasparcolor Processing**Formulae****Developer**

Metal	12 oz.
Sodium Sulphite (Anhyd.)	17 lb. 13 oz.
Hydroquinone	5 lb. 1 oz.
Sodium Carbonate	11 lb. 4 oz.
Potassium Bromide	2 lb. 8½ oz.
Water to make	75 gallons
Time, 9 minutes	
Temp. 65° F.	
Gamma 2·2	

Fixation

Hypo	6 lb.
Sodium Metabisulphite	6½ oz.
Water to make	2 gallons
Time, 9 minutes	

Dye Bleach

Thiocarbamide	17 lb. 8 oz.
Potassium Chrome Alum	12 lb. 8 oz.
Hydroquinone	7 lb. 8 oz.
Sulphuric Acid	565 c.c.
Water to make	25 gallons
Time, 11 minutes	
Temp. 68° F.	

Bleach Bath

Copper Sulphate	25 lb.
Sodium Chloride	25 lb.
Hydrochloric Acid	284 c.c.
Water to make	25 gallons
Time, 5½ minutes	

Sound Track Redeveloper

Metal	10 gm.
Sodium Sulphite (Anhyd.)	120 gm.
Hydroquinone	30 gm.
Caustic Soda	50 c.c. (40% Solution)
"Nekal"	10 c.c.
Dextrin	200 gm.
Water to make	400 c.c.
Time, 1 minute	

Fixation (Second)

Hypo	6 lb.
Potassium Metabisulphite	6½ oz.
Water to make	2 gallons
Time, 6 minutes	

Any variation in the final colour gamma of the respective layers must be compensated by choice of such gammas in the master positives that the product of the respective gammas shall be identical.

UNITED STATES PATENTS ASSIGNED TO CHROMOGEN
INCORPORATED OR BELA GASPAR

Reissue 21,513 (original 1,956,017—Apr. 24, 1934)	2,221,793—Nov. 19, 1940
1,956,122—Apr. 24, 1934	2,223,008—Nov. 26, 1940
1,985,344—Dec. 25, 1934	2,241,413—May 13, 1941
1,986,054—Jan. 1, 1935	2,255,463—Sept. 9, 1941
1,988,891—Jan. 22, 1935	2,258,755—Oct. 14, 1941
2,004,625—June 11, 1935	Reissue 22,308 (original 2,270,118—Jan. 13, 1942)
2,020,775—Nov. 12, 1935	2,271,176—Jan. 27, 1942
Reissue 21,099 (original 2,025,658—Dec. 24, 1935)	2,274,782—Mar. 3, 1942
2,028,279—Jan. 21, 1936	2,278,984—Apr. 7, 1942
2,041,827—May 26, 1936	2,279,309—Apr. 14, 1942
2,042,253—May 26, 1936	2,281,149—Apr. 28, 1942
2,046,067—June 30, 1936	2,281,281—Apr. 28, 1942
2,049,005—July 28, 1946	2,283,361—May 19, 1942
2,055,407—Sept. 22, 1936	2,296,843—Sept. 29, 1942
2,062,304—Dec. 1, 1936	2,310,226—Feb. 9, 1943
2,071,688—Feb. 23, 1937	2,310,227—Feb. 9, 1943
2,074,259—Mar. 16, 1937	2,310,228—Feb. 9, 1943
2,075,190—Mar. 30, 1937	2,312,543—Mar. 2, 1943
2,075,191—Mar. 30, 1937	2,313,993—Mar. 16, 1943
2,080,041—May 11, 1937	2,316,782—Apr. 20, 1943
2,088,523—July 27, 1937	2,316,803—Apr. 20, 1943
2,107,605—Feb. 8, 1938	2,317,184—Apr. 20, 1943
2,119,323—May 31, 1938	2,317,369—Apr. 27, 1943
2,125,015—July 26, 1938	2,318,007—May 4, 1943
2,132,154—Oct. 4, 1938	2,319,984—May 25, 1943
2,136,143—Nov. 8, 1938	2,320,005—May 25, 1943
2,137,336—Nov. 22, 1938	2,320,358—June 1, 1943
2,155,894—Apr. 25, 1939	2,321,195—June 8, 1943
2,166,049—July 11, 1939	2,331,492—Oct. 12, 1943
2,172,307—Sept. 5, 1939	2,333,126—Nov. 2, 1943
2,172,308—Sept. 5, 1939	2,336,560—Dec. 14, 1943
2,178,167—Oct. 31, 1939	2,340,656—Feb. 1, 1944
2,183,393—Dec. 12, 1939	2,341,034—Feb. 8, 1944
2,183,394—Dec. 12, 1939	2,344,084—Mar. 14, 1944
2,183,395—Dec. 12, 1939	2,345,193—Mar. 28, 1944
2,193,931—Mar. 19, 1940	2,347,119—Apr. 18, 1944
2,207,631—July 9, 1940	2,348,735—May 16, 1944
2,217,544—Oct. 8, 1940	2,348,894—May 16, 1944
2,217,899—Oct. 15, 1940	2,353,661—July 18, 1944
2,219,304—Oct. 29, 1940	2,356,759—Aug. 29, 1944
2,219,305—Oct. 29, 1940	2,357,590—Sept. 5, 1944
2,219,306—Oct. 29, 1940	2,361,541—Oct. 31, 1944
2,219,987—Oct. 29, 1940	2,361,936—Nov. 7, 1944
2,219,988—Oct. 29, 1940	2,367,936—Jan. 23, 1945
2,220,123—Nov. 5, 1940	2,368,463—Jan. 30, 1945
2,221,792—Nov. 19, 1940	2,368,647—Feb. 6, 1945
	2,387,754—Oct. 30, 1945

THE PRINCIPAL ENGLISH PATENTS OF DR. BELA GASPAR

354,167	434,305	500,098
369,616	434,875	503,330
379,679	441,411	503,379
395,718	441,983	506,385
397,159	444,669	507,151
397,170	445,806	507,152
397,188	445,959	507,211
397,192	446,206	507,357
406,013	446,392	507,418
406,294	448,161	507,485
408,991	450,685	510,884
409,270	458,256	515,998
409,287	458,304	516,883
412,949	464,852	517,328
412,950	468,508	517,480
413,688	468,509	517,559
415,040	472,644	518,213
415,756	472,981	518,477
416,566	478,735	519,790
416,660	480,854	520,527
416,666	483,366	520,529
417,444	483,463	520,573
417,588	483,464	520,575
418,368	485,552	521,961
418,581	488,093	522,190
419,810	490,451	522,611
421,534	491,856	522,696
421,727	492,672	523,179
424,563	492,711	523,507
426,260	494,341	529,117
428,158	496,558	529,279
430,991	496,559	535,130
432,464	498,461	560,373

The Splendicolor Process

A three-colour subtractive process. Worked in 1928.

Camera.—No published account.

Printing.—Cyan printing on one side by iron toning. The yellow and magenta were printed on the other side by "dyed bichromate." Presumably the surface was twice coated with gelatine, sensitized with bichromate, developed as a relief, and dyed; or the dyeing may have been done by a process similar to Pinatype.

Kodachrome¹

(Eastman Kodak Company, Rochester, N.Y., U.S.A.)

Classification.—Integral layer (tripack) three-colour subtractive process.

Introduction.—First introduced in 1935, this was the earliest of the integral layer processes to become commercially available. The present material provides colour photographs possessing high transparency, splendid colour range, and faithful reproduction. In the form of 8-mm.

¹ The data in the description which follows is largely derived from the publications of Eastman Kodak, by whose courtesy it is included.

and 16-mm. reversal film it has become deservedly popular all over the world. In the form of 16-mm. and 35-mm. film, Kodachrome is being employed increasingly as the original record for Technicolor 35-mm. positive prints; 35-mm. separation negatives must first be made, and from these the 35-mm. positive matrix imbibition films are printed. Kodachrome film is also frequently employed in the U.S. as an original record from which black-and-white release prints can be made by the duplicate negative release positive print method in substandard laboratories. Release printing on 16-mm. Kodachrome stock is carried out on a large scale in the U.S., the processing being completed at the Eastman laboratories. Processing of Kodachrome is reserved to the manufacturers, no detailed formulæ having been released for publication. Projectors of special design are used to project 3 in. \times 4 in. slides in Kodachrome for background projection in the U.S.

Camera.—Normal.

Projection.—Normal.

Printing.—Normal, with suitable colour grading.

Structure.—Cellulose butyrate safety-film base coated with three emulsion layers separated with gelatine interlayers. The sensitizing of the emulsion layers is such as to give separation negatives recording spectral regions substantially identical to those obtained with standard tricolour Wratten filters. The top emulsion is blue sensitive; below this is the first gelatine interlayer, a yellow filter to cut out further penetration of blue light; the middle emulsion is green sensitized, the second interlayer is *plain gelatine*; the bottom emulsion is red sensitized and without green sensitivity. The film base bears the usual antihalation backing. No colour couplers are incorporated in the Kodachrome emulsion layers, the coupling agents being present with the developer, which yields dyes plus the developed silver (Fig. 239).

Chemistry of Colour Coupling Developers.—The general principle of colour development is that the dyestuffs forming images are produced by the effect of an oxidizing agent on a mixture of a suitable developing agent and coupler, and that the oxidizing agent may be the exposed *silver bromide* of a photographic emulsion. One molecule of dye is produced for every 4 atoms of reduced silver.

In some instances the developer may be the coupler. This is known as "primary" colour development.¹ In other cases this process is known as "secondary" colour development.² (1)

¹ *Primary Colour Development.*—This is the type in which the oxidation product of a single developing agent is itself an insoluble dyestuff which is deposited on the site of the developed silver image.

² *Secondary Colour Development.*—Coloured images are obtained in the presence of a coupling developer and a colour coupler. In most instances any substituted or unsubstituted *p*-amino-aniline may be used as the developer. The dyes thus derived belong in the main to two classes, indoaniline (generally blues) or azomethine (generally magenta and yellow).

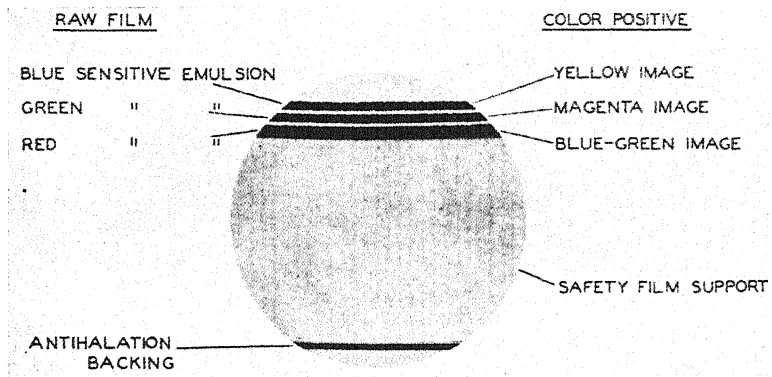
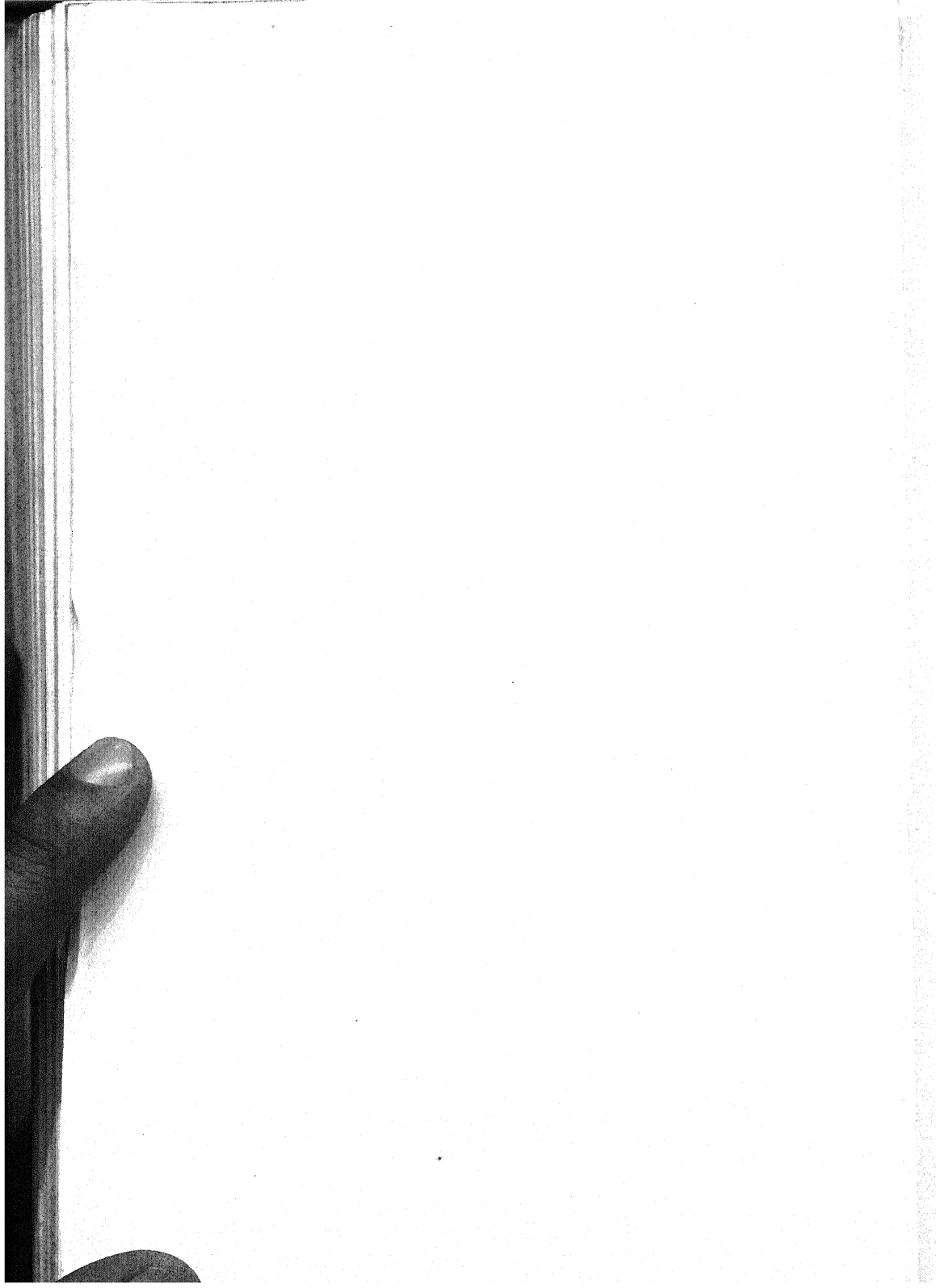
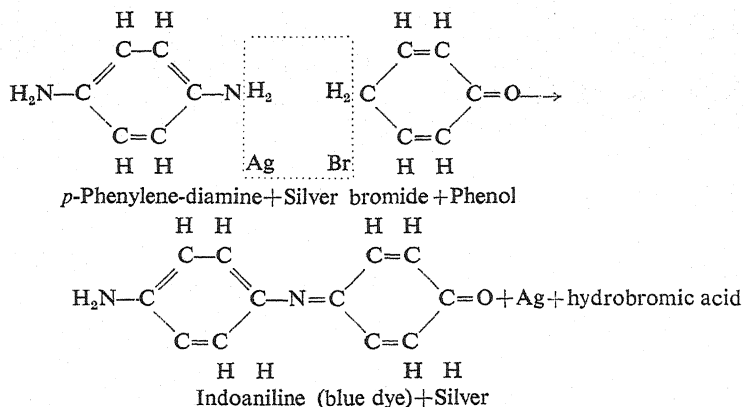


FIG. 239.—Section, Kodachrome film.



As we have previously noted, Rudolf Fischer (2) in 1912 discovered that paraphenylene diamine in the presence of an oxidizing agent will combine with certain derivatives of phenol to yield dyes of the indo-phenol or azine class. Cyan dyes are usually obtained by aromatic hydroxy-bodies, yellows by acetoacetic ester derivatives, and magentas by the use of heterocyclic rings such as pyrazolone or substituted acetonitriles. The oxidation arises from the exposed silver bromide. An enormous amount of work has been lavished on this branch of chemistry during the last ten years, and the known couplers and developers are now very numerous indeed. The fundamental reactions may be represented thus:



Reproduction of Colours in Projection.—Diagram A (Fig. 240) shows how the film looks in cross-section after camera exposure and first development of the emulsion layers to negative images. Diagram B shows the appearance of the film after coupler development has been completed. In Diagram C the silver has been removed and white light from a projection lamp is transmitted through the film to a screen, giving an image in the colours of the original subject. A complete understanding of the manner in which screen images in colour are secured with Kodachrome can best be achieved by tracing the passage of light through the dye layers. It is suggested that the reader follow closely the right-hand side of the diagram while reading the following paragraph.

White light (on the screen) is secured by the unobstructed passage of light from the projector lamp to the screen. *Red* light results when a ray of white light is filtered by successive layers of magenta and yellow dye. The magenta layer absorbs green, leaving only blue and red. The yellow layer in turn absorbs blue, leaving only red. To secure *green* light, the blue-green layer absorbs red, leaving green and blue. The yellow layer then absorbs blue, and green light passes to the

screen. For *blue* light, the blue-green layer again subtracts red, leaving blue and green. The magenta layer then absorbs the green, leaving only blue. Intermediate colours and mixtures are secured by partial absorptions at each layer. Heavy dye deposits in all three layers subtract light of all colours, resulting in a black screen image.

Processing.—It was announced in December 1940 by Dr. Mees (3) that the Kodachrome processing procedure was no longer based upon the controlled diffusion principle, but had adopted the re-exposure of each layer separately permitting its individual colour development. The sequence of operations might be that described in E.P. 519,419 (Addition to 507,841). The method may be described as differential re-exposure by selective layer-sensitization. Retention of the original red sensitizing during processing is necessary, and the front layer is sensitized to red during processing, the film being selectively sensitized and exposed to coloured light as part of the processing sequence, such that only one layer at a time is affected. The steps are as follows:—

<i>Step.</i>	<i>Description.</i>
1	The exposed film is developed to a negative
2	Washed
3	Re-exposed through the back to strong red light and developed in a cyan coupler developer
4	Washed
5	Top layer is sensitized to red by a slowly penetrating sensitizer (dye in glycerol); the blue-green image being unaffected
6	The re-sensitized film is then exposed from the front to a strong red light and developed in a yellow coupler developer Note: Stages 5 and 6 may have been substituted by re-exposure of the front layer to blue light
7	Washed
8	Exposed from both sides to white light and developed in a magenta coupler developer
9	Washed
10	Silver removed. (Farmer's reducer.)
11	Washed and dried

Loss of sensitivity in the first developer is restored by adding α -naphthylamine to the *p*-phenylenediamine. Wandering is prevented by adding less than 1.5 per cent. sodium or pot. perchlorate to the various baths and wash water.

Substances which are capable of preferential absorption to unexposed silver halide would displace the sensitizing dye and so developers must be free of such agents; further, the developer should have no solvent action on the emulsions (notwithstanding the fact that silver solvent developers are usually employed for reversal), therefore sulphate must be avoided and sodium formaldehyde sulphonylate substituted. Also

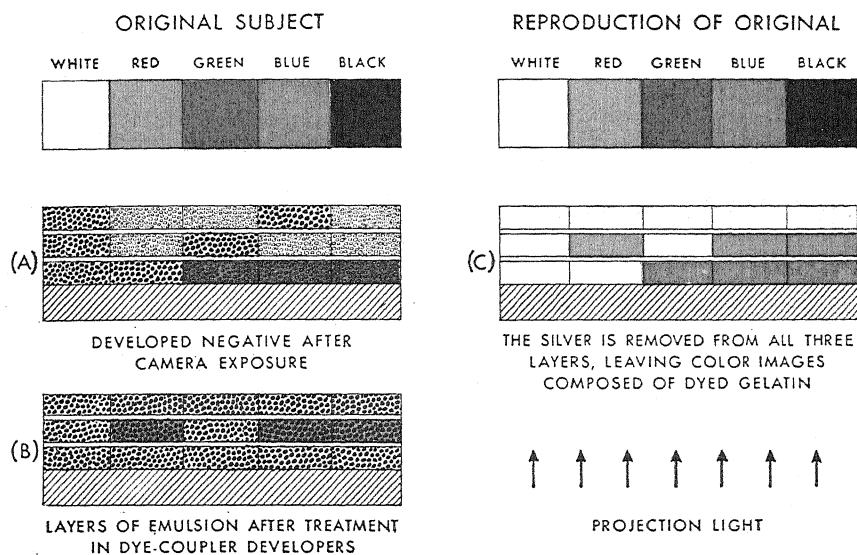


FIG. 240.—Reproduction of colours by Kodachrome film.

[Facing p. 430

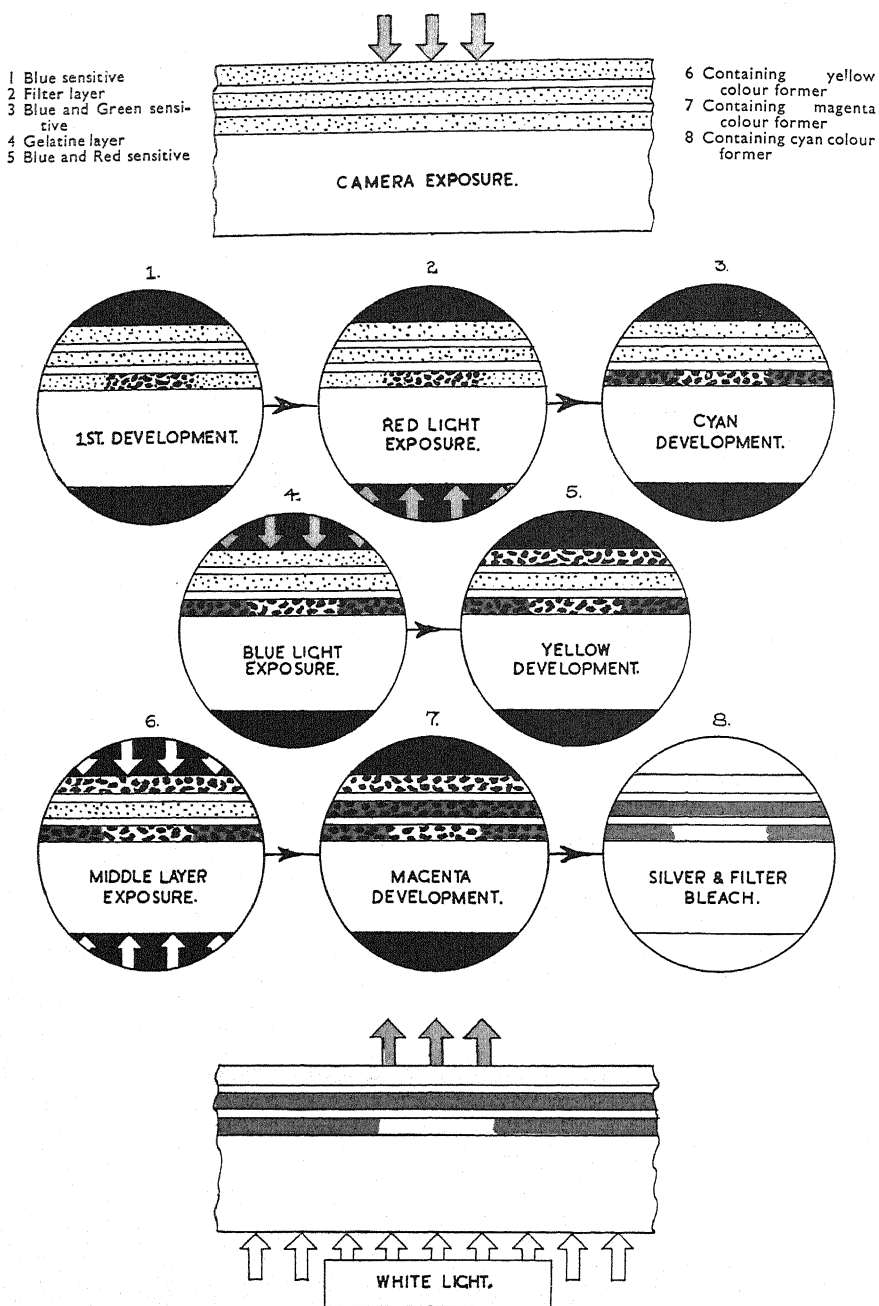


FIG. 241A.—Kodachrome film processing sequence. A cross-section of the film is shown at each main processing stage, but washes, rinses and stop baths are omitted.

emulsions must not have a high iodide-bromide ratio as liberated soluble iodide during development desensitizes unexposed grains in the vicinity. A first developer may be:

Metol	3 to 10 gm.
Sodium formaldehyde sulfoxylate	3 to 10 gm.
Triethanolamine	3 to 15 gm.
Sodium perchlorate	0 to 5 gm.
Water	1 litre

In the Technicolor Patent E.P. 556,631, which deals with a protective lacquer for sound tracks, there is an interesting description which is said to be typical of the procedure for developing Kodachrome (see Fig. 241A):

" The monopack film illustrated in Fig. 1 comprises the usual transparent backing A and three layers of emulsion, comprising a red-sensitive layer R, a green-sensitive layer G, and a blue-sensitive layer B. While the respective layers may be exposed either successively or simultaneously to the different color aspects of the beam, a typical printing method comprises exposing the three layers simultaneously by printing from another color developed film or other kind of color film. Either before or after the pictures are printed the sound track may be printed. After the sound track has been printed the sound track zone is covered with a coating C of lacquer or varnish which is opaque, flexible, has good adhesive quality, is impervious to processing liquids, fast drying and easily redissolvable. After the sound track zone has been coated the gelatin throughout the picture zone may be hardened. Then the picture components in the three layers are simultaneously developed to silver and, if the layers have been exposed from the top, the developed records will appear in the upper strata of the respective layers. In printing from a positive film these negative records would of course be negative components.

" The first stage in the series of stages of color development consists in exposing the remainder of the light-sensitive silver salt in the lower stratum of the red-sensitive layer R. By effecting this exposure with red light from the bottom, only the red-sensitive layer R is affected: and by excluding the red light from the sound track zone the red-sensitive layer is not affected throughout that zone. After the red-sensitive layer has been flashed with red light the exposed silver salt in the lower stratum of the layer R is color developed in well-known manner to produce a cyan colored positive component in the layer R. The upper layer B is then flashed from the top with blue light, the light being excluded from the sound track by the aforesaid opaque coating C, after which the exposed silver salt in the lower stratum of the B layer is color developed to produce a yellow positive picture component. At this stage, no developable silver halide would remain in either of the layers B and R if the previous developing processes had been carried

to completion. However, it has been found advantageous to use cyan and yellow developers which are too weak to carry the development to completion. After the cyan and yellow positive components have been developed as aforesaid it is therefore preferable to subject the film to a suitable black-and-white developer to convert the exposed silver halide remaining in layers B and R into silver.

" The next step consists in color developing a magenta positive component in layer G. While this may be effected by first re-exposing the layer and then color developing the exposed silver halide, the magenta positive is preferably formed by adding a fogging agent to the magenta developer in well-known manner, thereby eliminating the step of re-exposing the G layer.

" After the three positive components have been color developed by the aforesaid reversal method the film is first bleached to convert all the reduced metallic silver into a compound which is soluble in the fixing solution that follows bleaching. The fixing solution also removes any unexposed silver halide remaining in the picture zone. Inasmuch as the sound track zone is still covered by the aforesaid protective coating, the silver halide in the sound track zone is not removed in this fixing step.

" The next step consists in removing the protective covering C by dissolution of any lacquer or varnish solvent which does not affect the picture zone. Inasmuch as the sound track zone is to be treated with aqueous solutions after the coating is removed and inasmuch as lacquer and varnish solvents are usually immiscible with water after the coating has been dissolved off the film is first washed with some liquid such as isopropyl alcohol which is miscible both with the solvent and with water, after which the alcohol is removed in a bath of water. After the sound track zone has been thoroughly washed the sound track is developed with an ordinary black-and-white developer. The unexposed and unreduced silver halide is removed from the sound track zone with an ordinary fixing solution. Thereafter the processing is completed by washing and drying the film.

" Suitable compositions for the aforesaid coating and coating remover comprise:

COATING

				%
Nitrocellulose (30-40 second)	..	..	..	10
Ester Gum ..	..	..	..	5
Dibutyl Phthalate ..	..	..	..	5
Butyl Acetate ..	..	..	..	23
Butyl Alcohol ..	..	..	..	12
Amyl Acetate ..	..	..	..	8
Ethyl Alcohol ..	..	..	..	8
Toluene ..	..	..	..	27
Carbon Black ..	..	..	..	2

KODACHROM METHOD OF CONTROLLED DIFFUSION COMBINED WITH DYE DEVELOPMENT.

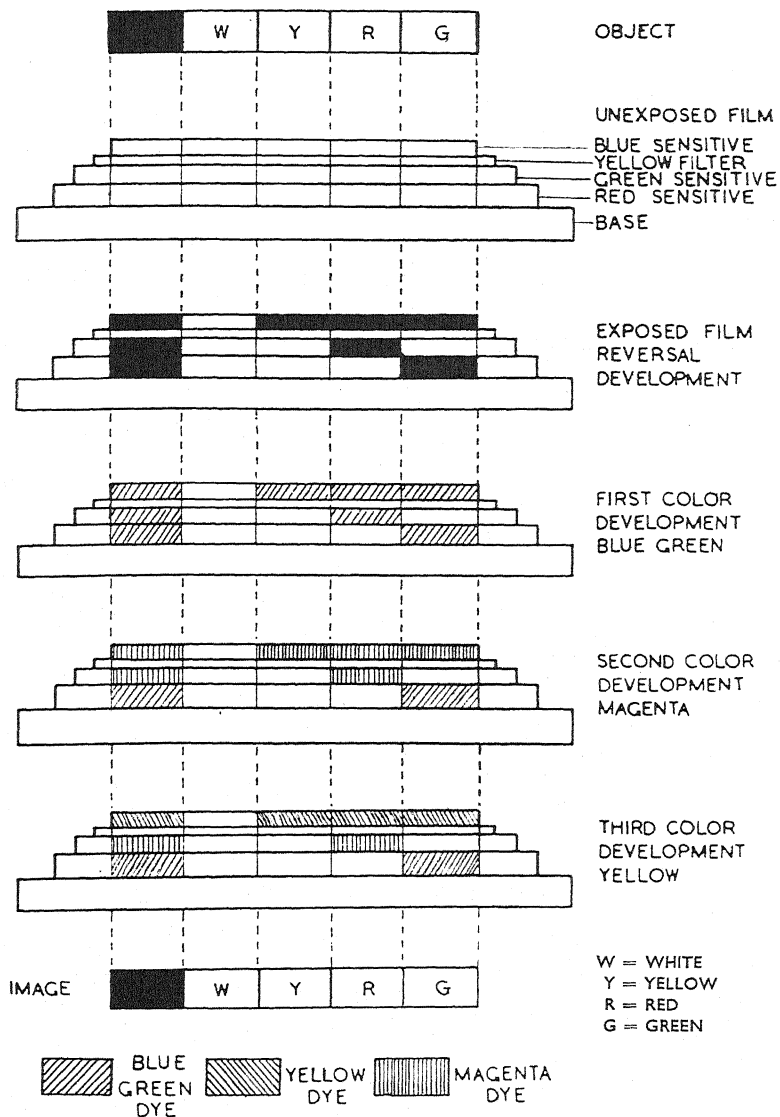


FIG. 241.

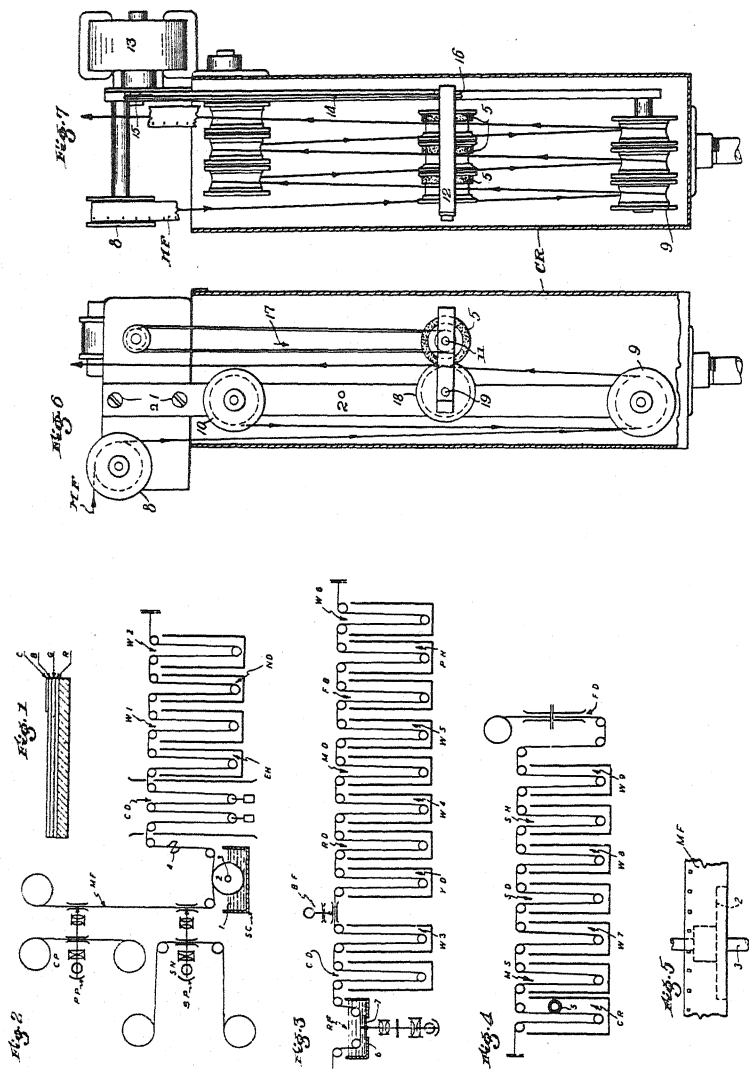


FIG. 241A.—Technicolor Patent E.P. 556,631. (See p. 431).

COATING REMOVER					%
Butyl Acetate	..	..	..	..	30
Butyl Alcohol	..	..	..	..	15
Amyl Acetate	..	..	..	..	10
Ethyl Alcohol	..	..	..	..	10
Toluene	..	..	..	..	35

In the old Kodachrome controlled diffusion technique all three layers were colour developed cyan after reversal and the top two bleached in quinone and potassium bromide. The bleached layers were redeveloped magenta and the top layer alone bleached. This was finally developed to yellow (Fig. 241).

16-mm. Kodachrome Duplicates.—Duplicates are available from either 16-mm. silent or sound Kodachrome. Orders for silent duplicates require no special preparation by the user. In the case of 16-mm. Kodachrome duplicates the sound record submitted to the manufacturers for printing must be either a 35-mm. or a 16-mm. matched positive print of high quality. When a sound track is sent in for duplicating, the proper starting point on both the sound track film and the 16-mm. Kodachrome original should be indicated clearly and accurately to assure synchronization.

Titling and Copying Service in 16-mm. Kodachrome. *Copying Service.*—Pictures, drawings, maps, etc., from $1\frac{5}{8} \times 2\frac{1}{2}$ to 11×14 in. can be copied and supplied by the makers on 16-mm. Kodachrome.

Titles.—Supplied with a red background and a black-and-yellow border. The order should specify whether the titles are for use with an original or duplicate. These services are available only from Rochester, N.Y.

Kodachrome Types.—Kodachrome is supplied for substandard motion pictures in two types:

Kodachrome Film, Daylight Type	} 8-mm. and 16-mm. motion picture film.
Kodachrome Film, Type A	

The colour balance of the Daylight Type is adjusted to give the best rendition of the subject in bright sunlight on a clear day—that is, an illumination which is the equivalent of noon sunlight plus skylight, the colour-temperature of which is approximately 6,100° K.

Kodachrome Type A is colour balanced for use with a Photoflood Lamp having an approximate colour-temperature of 3,400° K.

Storage after Exposure before Processing under Tropical Conditions.—When tropical packages are opened the film soon comes into moisture equilibrium with the air. If left in the camera under humid conditions, it may deteriorate rapidly. Therefore the packages should not be opened until necessary, and the film should then be exposed and sent for processing as quickly as possible. If subjected to humid air, the film must be resealed in tropical packing unless it is first dried.

If several days or weeks are to elapse before processing, the film should be dried, resealed in the original package, and kept as cool as possible. Drying can be accomplished by placing the film in a sealed can together with a desiccating agent such as silica gel, rice dried by browning in an oven, or dried tea leaves. The drying agent should be separated from the film by a porous partition. Two Davco Silica Gel Air Dryers (the Davison Chemical Corporation, Baltimore, 3, Maryland, U.S.A.), 4 oz. of silica gel, or two 2 lb. of dried rice or tea leaves, will dry ten 100-ft. rolls of 16-mm. Kodachrome film.

Filters

Kodachrome Haze Filter (Wratten No. 1).—Absorbs ultra-violet radiation of shorter wavelength than 380 $m\mu$. Used with Daylight Type film for distant mountain views, high-altitude aerial shots, exteriors under an overcast sky or in shade illuminated by blue sky. No exposure increase required.

Wratten No. 2A.—For still warmer colour rendering. No exposure increase required.

Wratten No. 85.—For use of Kodachrome Type A in daylight. The practice is not recommended by Kodak. For scenic shots taken at high altitudes under hazy conditions, Type A film with Wratten A Filter gives somewhat better rendition of colour and distant objects than Kodachrome Daylight Type even with the haze filter. This filter absorbs ultra-violet.

Wratten No. 80.—For exposure of Kodachrome Daylight Type by Photoflood illumination. Requires four times the exposure of Type A with Photoflood. Colour rendition not so good.

Kodak Pola-Screens.—Polaroid filters are used to darken blue skies and to subdue non-metallic reflections. One stop greater than normal exposure required.

Lighting

Lamps.—For use with Type A, Mazda Photoflood Lamps Nos. 1, 2, and R-2 are recommended.

DATA—KODACHROME FILM, DAYLIGHT TYPE

General Properties: For general outdoor use in substandard motion picture cameras. Duplicates are available from 16 mm. reversal originals.

Rolls available in 8- and 16-mm. Film.

Use.

50-, 100-ft. rolls	..	..	All 16-mm. cameras
200-ft. rolls	..	..	For 200-ft. magazine of Ciné-Kodak Special
50-ft. magazines	..	..	Magazine Ciné-Kodak, Filmo 141, Zeiss Movikon K
100-, 200-, 400-ft. rolls	..	..	Single-row perforations for 16-mm. sound pictures
25-ft. rolls	..	..	Ciné-Kodak 8's and other 8-mm. cameras accommodating film in the 16-mm. widths
25-ft. magazines	..	..	Magazine Ciné-Kodak 8

SUBTRACTIVE PROCESSES

<i>Recommended Meter Settings.</i>	<i>Weston.</i>	<i>G.E.</i>	<i>A.S.A.</i>
Daylight	8	12	10
Tungsten	3*	5*	4*

* With Kodachrome Filter for Photoflood.

Filters.

Photoflood	Permits use of Daylight Type in Photoflood light
Haze Filter	Absorbs ultra-violet, reducing distant haze
Kodak CC-33	For use with daylight fluorescent lamps
Kodak CC-23	White-flame carbon arcs

Purpose.

Daylight Exposure Table: Substandard motion picture cameras with 8-mm. and 16-mm. Kodachrome at 16 frames per second ($\frac{1}{30}$ second shutter speed).

<i>Lighting.</i>	<i>Basic Exposure for Average Subjects.</i>	<i>Light-Coloured Subjects.</i>	<i>Dark-Coloured Subjects.</i>	<i>Side-Lighted Subjects.</i>	<i>Back-Lighted Subjects.</i>
Bright, direct sunlight	<i>f/8</i>	Between <i>f/8</i> and <i>f/11</i>	Between <i>f/5.6</i> and <i>f/8</i>	<i>f/8*</i>	<i>f/5.6*</i>
Weak, hazy sun, no distinct shadows cast	<i>f/5.6</i>	Between <i>f/5.6</i> and <i>f/8</i>	Between <i>f/4</i> and <i>f/5.6</i>		
Sky overcast, cloudy, but bright	<i>f/4</i>	Between <i>f/4</i> and <i>f/5.6</i>	Between <i>f/2.8</i> and <i>f/4</i>		
Open shade on bright day	<i>f/2.8</i>	Between <i>f/2.8</i> and <i>f/4</i>	Between <i>f/1.9</i> and <i>f/2.8</i>		

* Assuming shadow areas are unimportant. With close-ups having important shadow areas, use one full stop larger.

DATA—KODACHROME FILM, TYPE A

General Properties: For use with high-efficiency tungsten lamps (Photoflood Type).

Rolls available in 8- and 16-mm. Film.

50-, 100-ft. rolls ..	Ciné-Kodaks and other 16-mm. cameras
200-ft. rolls	200-ft. magazine of Ciné-Kodak Special
50-ft. magazines ..	Magazine Ciné-Kodak, Filmo 141, Zeiss Movikon K
50-ft. packettes ..	Simplex Pockette and Filmo 121
100-, 200-, 400-ft. rolls ..	Single-row perforations for 16-mm. sound recording
25-ft. rolls	Ciné-Kodak 8's and other 8-mm. cameras accommodat-
	ing film in the 16-mm. widths
25-ft. magazines ..	Magazine Ciné-Kodak 8

Use.

COLOUR CINEMATOGRAPHY

<i>Recommended Meter Settings.</i>	<i>Weston.</i>	<i>G.E.</i>	<i>A.S.A.</i>
Daylight	8*	12*	10*
Tungsten	12	20	16

* With Kodachrome Type A Filter for daylight.

<i>Filters.</i>	<i>To permit Exposure by</i>
Type A Kodachrome	Daylight
Filter for daylight	
Kodak CC-15	Wire-filled or shredded-foil Photoflash lamps
Kodak CC-4	3,200° K. lamps
Kodak CC-34	White fluorescent lamps

PHOTOFLOOD EXPOSURE TABLE—SUBSTANDARD MOTION PICTURE CAMERAS

With 8-mm. and 16-mm. Kodachrome Type A, operating at 16 frames per second ($\frac{1}{30}$ second shutter speed), using Kodaflectors with No. 1 Photoflood lamps.

Number of No. 1 Photoflood lamps and distance from lamps to subject	2 at 9 ft. or 3 at 11 ft. or 4 at 13 ft.	2 at 6½ ft. or 3 at 7½ ft. or 4 at 9 ft.	2 at 4½ ft. or 3 at 5½ ft. or 4 at 6½ ft.	2 at 3 ft. or 3 at 3½ ft. or 4 at 4½ ft.
	<i>f</i> /1.9	<i>f</i> /2.7 or <i>f</i> /2.8	<i>f</i> /4	<i>f</i> /5.6
Diaphragm opening and camera speed	Normal speed or <i>f</i> /2.8 Half speed	Normal speed or <i>f</i> /4 Half speed	Normal speed or <i>f</i> /5.6 Half speed	Normal speed or <i>f</i> /8 Half speed

Kodachrome as Original Material for Black-and-White Prints.—Kodachrome is increasingly used in the U.S. as an original record material to be used in preference to black-and-white 16-mm. negative. It has appreciably lower contrast than any fine-grain reversal film, although from a production point of view its slower speed is unfortunate.

Black-and-White 16-mm. Intermediate Negative from Kodachrome Original for making Fine-Grain 16-mm. Release Prints.—This practice is common in the U.S. W. H. Offenhauser (4) has stated that for the intermediate panchromatic fine-grain dupe negative Eastman stock 5203 is usually employed. The resolving power of this film is 110 lines per mm. in an SD-21 developer at a IIb control gamma of 0.65 (development 6 minutes). In printing on fine-grain Eastman positive 5302 a filter is used to limit the exposing light to wavelengths shorter than 5,000 Å. This helps to reduce contrast and improve definition and grain.

The print timing turns out to be identical to that when making a Kodachrome duplicate.

Kodachrome Resolving Power.—Kodachrome has a resolving power of 75 lines per mm.

Sound and Kodachrome Emulsion Position.—The standard position

in a 16-mm. projector is for the emulsion to face the screen. Most 16-mm. combined Kodachrome duplicates have the non-standard emulsion position—namely, the emulsion faces the light-source. When projecting Kodachrome duplicates it is necessary to re-focus the picture. Thus the sound optics should also be re-focused. Only a few projectors possess means for accomplishing this. This situation occurs only in the case of contact printing.

Kodachrome Sound Track.—It is feasible to print excellent Kodachrome sound duplicates at the same time as black-and-white prints are being made, since Kodachrome sound duplicates are made from the original and a positive black-and-white sound track, while the black-and-white prints are made from a black-and-white duplicate negative of the picture and from the original negative sound track.

Printing 16-mm. Kodachrome Duplicates (Release Printing).—Printers used are generally step-contact type having the movement claw within a frame or two of the aperture. Light-changing is effected through notches in the original. A flat gate is used to avoid slip, which may be serious with a curved gate. Optical sound printing is preferred. A test duplicate is shipped to the Eastman Kodak Company at Rochester and prints are not authorized until after the test print has been inspected and corrections made (5). The timing strip used for printing Kodachrome duplicates can be used for making a black-and-white duplicate negative.

During the war excellent Kodachrome 16-mm. prints were made in England by optical reduction from 35-mm. Dufaycolor master prints made from the original 35-mm. Dufaycolor negative.

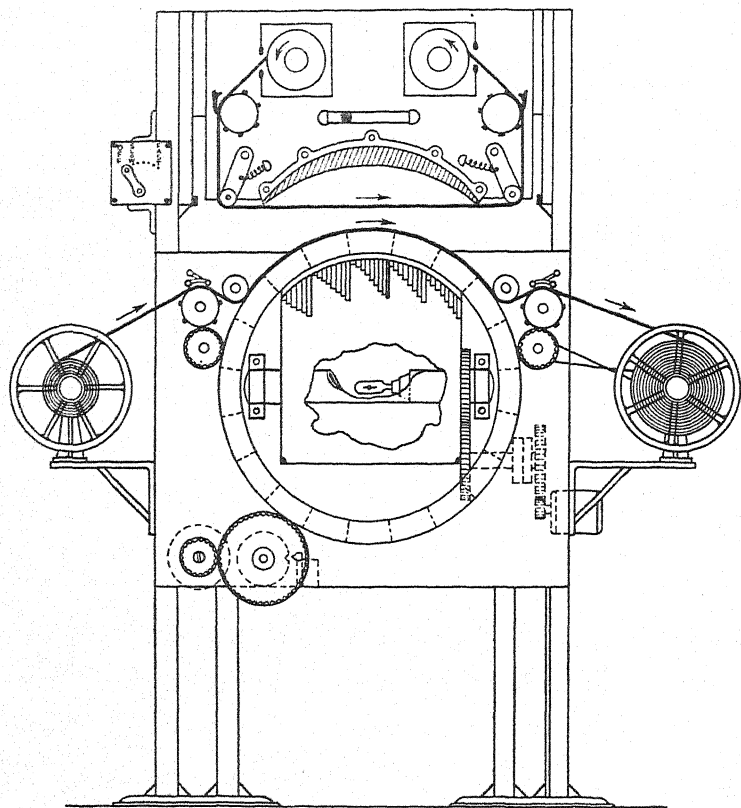
Colour Grading of Kodachrome Prints

The problem of testing for scene-to-scene colour balance and density has been solved in the U.S.A. by a new printer developed by the Acme Film Laboratories Inc. (Fig. 242). It was specified that each filter combination must be rendered in a series of densities. The complete strip provided by this apparatus is 55 frames in length; each filter pack being kept unchanged for eleven steps of density, each of 2 printer lights. The completed strip consists therefore of 5 filter combinations, each in 11 densities.

The exposure aperture is divided into 5 sections with provision for bringing the filter combinations, or packs, into the path of the light. To maintain uniformity of exposure over the whole strip the exposure aperture and the film transport mechanism is made spherical in shape with the top segment permitting free light passage from a centrally positioned lamp. Each of the 5 sections of the exposure aperture is partitioned into 11 sub-sections having the dimensions of a 16-mm. frame and each with its exposing light controlled by a rotating shutter.

COLOUR CINEMATOGRAPHY

With this apparatus deviations in the colour balance or speed of different emulsion batches can be detected and corrective measures taken; day by day variations of processing conditions can be noted and adjustments made.



Front View
(Covers removed)

FIG. 242.

Reference

LEAHY, WILSON, "A New Color Tester for 16-mm. Kodachrome Duplicates,"
Amer. Cinematographer, Vol. 28, 8 (Aug. 1947), p. 275.

Tentative Instructions for making 16-mm. Kodachrome Duplicates on Kodachrome Duplicating Film Code 5265

I. Picture Printing

A. General Instructions

Kodachrome Duplicating Film Code 5265 will produce high-

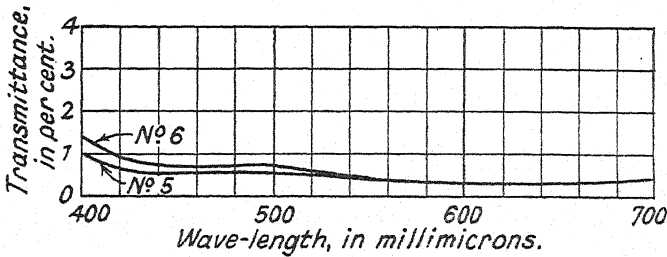


FIG. 243A.—Transmittance-wavelength characteristics of unexposed and developed Kodachrome. No. 5—EK 5265 Duplicating. No. 6—EK 5264 Type A.

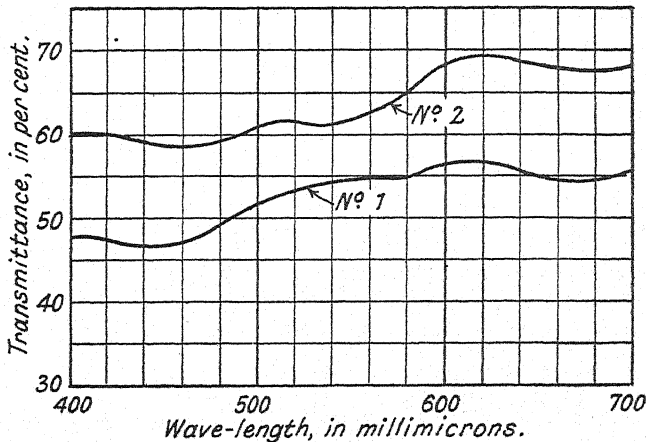


FIG. 243B.—Transmittance-wavelength characteristics for the Kodachrome duplication of a black-and-white film with EK 5265 and EK 5264. The conditions of test were: (1) Original used; EK 5365 uniformly exposed and developed to a density of 0.5. (2) Kodachrome used; No. 1—EK 5265 Duplicating Kodachrome; No. 2—EK 5264 Type A, Kodachrome. (3) Filters used; one Wratten 2A, one CC45, one CC44, one CC34, two 3.2 mm. Aklo. (4) Light source; T-10, 105-v., 500-watt lamp at approximately 80 volts. (5) Printer; DeBrie (contact-step printing at approximately 20 ft. per minute).

quality duplicates from 16-mm. Kodachrome originals when the printing conditions are properly selected, controlled, and balanced. High-quality printing equipment is necessary to produce a steady, high-definition picture. Both continuous and intermittent printers

have been found satisfactory. The voltage supplied to the printing lamp must be closely controlled to avoid density and colour balance fluctuation and drift. If duplicates are to be timed, a light change that involves voltage changes cannot be used, as voltage changes on the printer lamp produce changes in colour balance in addition to change in density (Fig. 243C).

The lamp used for printing should produce sufficient light at the aperture at a colour-temperature of approximately 2,900° K. The

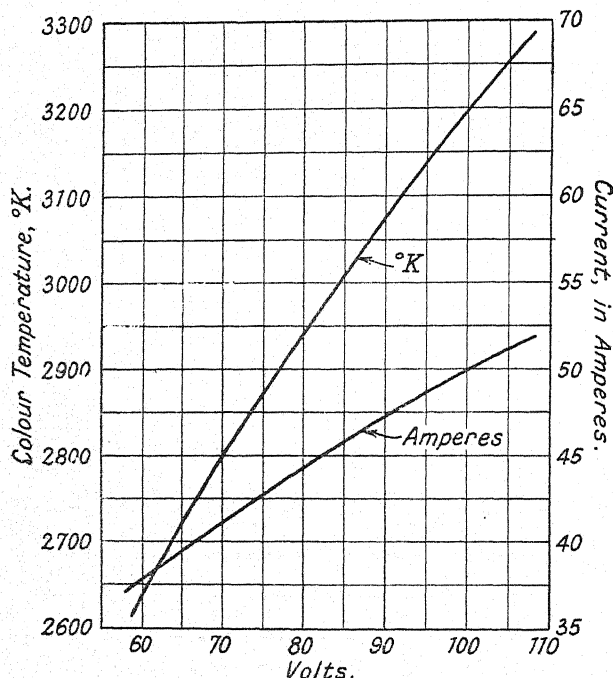


FIG. 243C.—Typical colour-temperature-volts-amperes characteristics of a 500-watt, 105-volt T-10 lamp.

colour-temperature can be established by the use of an Eastman Colour-Temperature Meter, or data relating colour-temperature to current can be obtained from the lamp manufacturers of the particular lamp used. The lamp current should then be adjusted by a suitable rheostat to produce the required colour-temperature. A reliable ammeter should be provided to monitor the lamp current continuously during printing to detect any voltage changes or lamp deterioration.

The choice of the type of lamp to be used will depend on the type of printer and the design and efficiency of the optical path. The light level at the aperture must be sufficient to produce the desired density

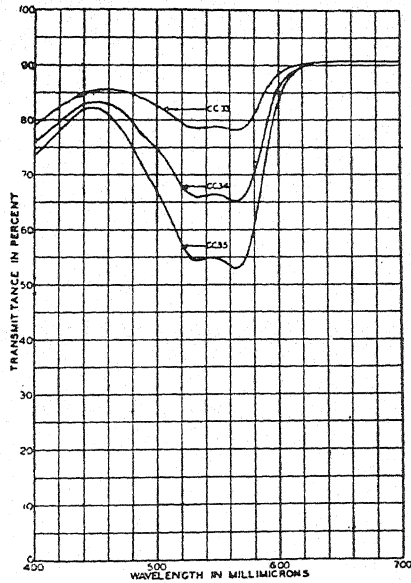


FIG. 243D.—Spectral transmissions of Eastman minus-green (magenta) compensating filters, CC-33—CC-34—CC-35.

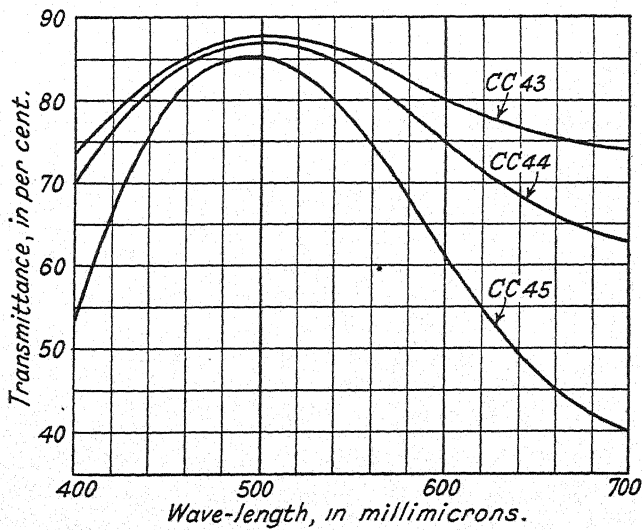


FIG. 243E.—Transmittance-wavelength characteristics of Eastman minus-red (cyan) compensating filters, CC-43—CC-44—CC-45.

specified below under the heading "Determination of Approximate Exposure." A level above the minimum is desirable, particularly if timing is to be accomplished, and this extra light can be reduced either by the mechanical timing equipment or by neutral densities.

To serve as an example, a particular light-source and filter set-up are as follows:

1. *Light-Source*.—A 7.5-amp., 10-volt Photo-Cell Exciter Lamp, operating at a colour-temperature of approximately 2,900° K. (obtained at about 6.6 amp.).

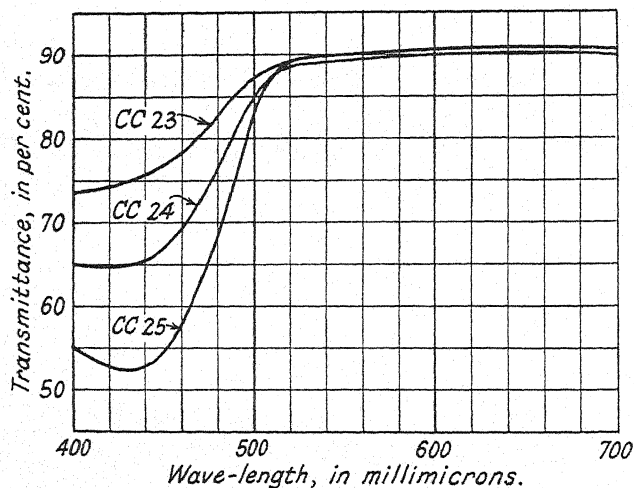


FIG. 243F.—Transmittance-wavelength characteristics of Eastman minus-blue (yellow) compensating filters, CC-23—CC-24—CC-25.

2. *Filters*.—

One Wratten No. 2A Filter (gelatine).

Two heat-absorbing Aklo Glasses, each 3.2 mm. thick.

One Eastman Colour-Compensating Filter CC-45 (gelatine).

One Eastman Colour-Compensating Filter CC-44 (gelatine).

One Eastman Colour-Compensating Filter CC-34 (gelatine).

(These filters are available from the Eastman Kodak Company.)

It should be noted that the light-source and filter combination specified above is given only to illustrate a combination that has given satisfactory results. Owing to variations in optical systems (even in printers of the same make), the above filter combination may have to be changed to fit the individual requirements. To introduce further corrections the following Eastman Colour-Compensating Filters will be found useful: CC-23, CC-24, CC-25, CC-33, CC-34, CC-35, CC-44, CC-43, CC-45. (See Figs. 243D-F.)

The table below gives the colour densities of all these filters and a neutral density value to be used for simultaneous exposure correction. It will be noted that the neutral density value of a filter is given as one-third of the colour value. This is not specific, but is included as a guide for correction of exposure.

3. Filter Factors.—

Filter No.	Colour Density.	Neutral Density Equivalent.
CC-23	0.06 (minus blue)	0.02
CC-24 Yellow ..	0.12 (" ")	0.04
CC-25	0.22 (" ")	0.07
CC-33	0.06 (minus green)	0.02
CC-34 Magenta ..	0.12 (" ")	0.04
CC-35	0.22 (" ")	0.07
CC-43	0.06 (minus red)	0.02
CC-44 Cyan ..	0.12 (" ")	0.04
CC-45	0.22 (" ")	0.07
2 pieces Aklo or Calorex Glass 3.2 mm. each	0.16 (minus red)	0.10

Gelatine filters should be tested and replaced at regular intervals to prevent colour changes caused by fading.

4. *Aklo Glass*.—Aklo Glass is an American product. A similar type of material made in Great Britain is Chance's ON 20, and this is equally suitable.

Aklo Glass is an infra-red (heat) absorbing glass. As a result the temperature of the glass will rise during operation unless free air circulation or an air stream is provided. The glass can be placed at any point between the light-source and the colour-compensating gelatine filters used for colour-temperature correction. It is preferable to have the gelatine filters as far beyond the Aklo Glass as possible in the light system. In this way the rise in temperature of the Aklo Glass will not be transmitted to the filters.

B. Instructions for setting up a New Printer not previously balanced for Kodachrome Emulsion Code 5265.

1. Determination of Approximate Exposure.—

- (a) Bring printer lamp to proper colour-temperature and add colour-compensating filters as outlined above under "Filters."
- (b) Place additional neutral density filter or filters in the exposing beam. These are removed for exposure of the film to be duplicated, as explained later.
 - (1) Use 1.20 neutral density for 5301 emulsion.
 - (2) Use 0.70 neutral density for 7302 emulsion.

- (c) Expose a short length of Eastman Ciné Positive Film (Code 5301 or 7302) in the printer directly to filtered printing light with the exposure time the same as intended for duplicating printing.
- (i) 5301 *Emulsion* (Ordinary 16-mm. Positive).—Develop a six-in. strip of the exposed 5301 film in fresh D-76 developer at 68° F. for 7 minutes to a gamma of 1.2, fix, wash, and dry. The density of this strip should be 0.55 ± 0.15 to give properly exposed Kodachrome duplicates on 5265 for normal originals. If a higher density than 0.55 is obtained on the first test, neutral density in excess of the 1.2 originally used should be added, or the mechanical light-modulating control should be changed until the 0.55 density on the test strip is obtained. If a density lower than 0.55 is obtained (with 1.2 neutral density in the printer), then the intensity of the light-source should be increased (either by the removal of neutral density, which is there in addition to the 1.2, by manipulation of the mechanical light control, or by the use of a higher-wattage lamp, if necessary) until 0.55 density on the test strip is obtained.
- (ii) 7302 *Emulsion* (16-mm. Fine-Grain Release Positive).—Develop a 6-in. strip of the exposed 7302 film in fresh D-76 developer at 68° F. for 7 minutes to a gamma of 1.80, fix, wash, and dry. The density of this strip should be 0.55 ± 0.15 to give properly exposed Kodachrome duplicates on 5265 emulsion for normal originals. The intensity of the light-source should be lowered or increased, if necessary, to obtain this density in the same manner as explained above for the 5301 emulsion.

2. *Tests for Colour Balance and Exposure.*—At the exposure level used to obtain the density of 0.55 ± 0.15 on Code 5301, remove the 1.20 neutral density (0.70 neutral density for Code 7302) from the beam and expose a series of colour and exposure variations on Code 5265 film, using a normally exposed original for duplicating.

A suggested set of colour variations is as follows:

- (a) Filter combination and exposure as above.
- (b) Condition (a)—CC-45.
- (c) Condition (a)—CC-45.
- (d) Condition (a)—CC-34.
- (e) Condition (a)—CC-34.
- (f) Condition (a)—CC-44—CC-34.
- (g) Condition (a)—CC-44—CC-34.

The test should then be sent in for processing.

3. *Determination of Printing Conditions for Final Correct Colour Balance and Exposure.*—When the processed test has been returned, it should be compared to the original, and the variation which most nearly matches the original should be chosen. If this is still not exactly correct for colour, it should be corrected on another test as follows:

<i>Colour Tendency to be corrected.</i>	<i>Method of Correction.</i>	
1. Too green	Increase minus green	
2. Too red	Increase minus red	
3. Too blue	Decrease minus green and minus red, or if not enough minus green and minus red in printer for this; add minus blue	
4. Too magenta	Decrease minus green or add minus red and minus blue	
5. Too blue-green	Decrease minus red	
6. Too yellow	Increase minus red and minus green	

This procedure is intended for properly exposed originals only and should give reasonably close results with a few tests.

II. Sound Printing

A. General Instructions

Both variable density and variable area sound tracks can be printed on 16-mm. Kodachrome either by contact printing 1-1 optical printing or by optical reduction printing from 35-mm. It is necessary to print from a suitable black-and-white print rather than from the negative. It is also satisfactory to print from a direct playback type of positive—that is, a positive made directly in the recorder for such purpose.

The printing machine used should have uniform motion and uniform aperture illumination. No particular filters are recommended, ordinary tungsten light being considered satisfactory. The amount of light required for printing sound on 5265 emulsion is approximately eight times the light level used on the same printing equipment when exposing regular positive type 5301, assuming that the sound track printing positive has about the same density as the negative used for the 5301 work.

The amount of light for printing the Kodachrome duplicating emulsion 5265 would be approximately twice that required for printing 7302 emulsion.

The correct printing level should be arrived at by sending printed samples of track in for processing. A listening test for quality and volume is satisfactory.

COLOUR CINEMATOGRAPHY

B. Control Densities and Gammas

The control densities and gammas of the various black-and-white steps prior to the final Kodachrome print are important factors in the quality and freedom from distortion of the final result. The following data have been determined experimentally from a large run of tests, but it should be considered as a guide rather than as a definite basis for all work. Cross-modulation and intermodulation studies are recommended to establish sensitometric controls for any particular set of conditions.

VARIABLE DENSITY (TUNGSTEN EXPOSURE)

<i>Original Negative.</i>			<i>Printing Positive.</i>		
<i>Film.</i>	<i>Density.</i>	<i>Gamma.*</i>	<i>Film.</i>	<i>Density.</i>	<i>Gamma.*</i>
1357	0.40-0.55	0.35-0.50	1301, 5301,	0.70-0.75	2.2
			or 1302, 7302	0.70-0.75	2.8
5357	0.40-0.55	0.35-0.50	5301	0.70-0.75	2.2
			or 7302	0.70-0.75	2.8

* Type IIB control gamma.

VARIABLE AREA (ULTRA-VIOLET EXPOSURE)

<i>Original Negative.</i>			<i>Printing Positive.</i>		
<i>Film.</i>	<i>Density.</i>	<i>Gamma.*</i>	<i>Film.</i>	<i>Density.</i>	<i>Gamma.*</i>
1357	1.9-2.2	2.2-2.5	1301, 5301, or 1302, 7302	2.0 (35 mm.)	2.2
				1.5-1.6 (16 mm.)	2.2
				2.0 (35 mm.)	2.8
				1.5-1.6 (16 mm.)	2.8
5357	1.9-2.2	2.2-2.5	5301 or 7302	1.5-1.6 (16 mm.)	2.2
				1.5-1.6 (16 mm.)	2.8
5372	2.35†-2.45†	2.6-2.8	7302	1.5-1.6 (16 mm.)	2.8

* Type IIB control gamma.

† Includes 0.25 density of blue base.

C. Direct Recorded Printing Positive Work

The densities and gammas suggested as a guide for direct recorded printing positive work appear below:

VARIABLE AREA (ULTRA-VIOLET EXPOSURE)

<i>Film.</i>	<i>Density.</i>	<i>Gamma.</i>
5372	1.25*-1.45*	2.6-2.8

* Includes 0.25 density of blue base.

**Kodachrome 16-mm. as the Original Record for Technicolor
35-mm. Releases**

The following describes the procedure originated by Del Frazier, of the Warner Brothers Studios, for using camera equipment and Kodachrome film in the production of short subject features to be released as standard 35-mm. Technicolor prints.

The *Ciné-Kodak Special*, equipped with 15-mm., 25-mm., and 50-mm. lenses, has served every purpose required and has not been found lacking in any respect. A large field professional viewfinder has been added to the left side of the camera, giving more speed and accuracy of operation and eliminating horizontal parallax.

A normal camera speed of 24 frames per second is used when recording sound in synchronism with the photography. A speed of 32 frames per second is used for photographing sport action shots to be presented with narration. For slow motion or shots of prolonged interest, such as fast swimming, diving, and golf action, etc., a Bell & Howell Speed camera operating at 128 frames per second is used. A third camera is carried as a cover for action while reloading magazines—an Eastman Model K camera with a 15-mm. fixed-focus lens carried in a convenient side pocket. Precautions should be taken in selecting group cameras with regard to the relation between sprocket holes and frame lines, which should be held to close tolerances so as to avoid frame shift when splicing and during subsequent projection.

A sturdy tripod should be used whenever possible, but in many instances work can be accomplished without one, giving more freedom of action. This is especially true in shots close to the ground or taken from tree-tops, or perhaps from a step-ladder. Scenes taken from fast-moving cars or motor-boats can be completed in the length of time it would take to fasten down a bulky 35-mm. camera. But then again one must be very careful, always holding the camera firmly against the body and breathing very lightly.

As in all other operations pertaining to the photography of 16-mm. pictures, great attention must be given to exposure, for the reason that an under- or over-exposure shifts the colour of the scene. In

addition, it is possible that a slight loss in rendition might occur in the Technicolor print as compared to the original Kodachrome, but this is negligible inasmuch as an audience is not in a position to make a direct comparison. A Weston reading of 8 is used in most instances, but wherever there is a great percentage of deep colours, blue sky, or heavy shadows, a slight overexposure (Weston 6) gives more latitude in making separations.

An important lesson learned is not to work with the 16-mm. film immediately after processing. When the soft-surfaced emulsion is enlarged to 35-mm. size and then enlarged further to the size of a theatre screen, all the scratches and finger marks become sadly obvious.

The principal advantages of editing a 16-mm. film enlarged to 35-mm. black-and-white are, first, the original Kodachrome needs no handling other than that required in printing the 35-mm. negative and in cutting to match the 35-mm. black-and-white pilot print. Second, the editor can work much faster, and with the same confidence as in regular 35-mm. production; the projection of his work can be seen in any available viewing room. To cut the original Kodachrome in the orthodox manner would entail endless splicing troubles, and the required handling of the film would ruin its value for reproduction.

The enlargement of the 16-mm. Kodachrome to 35-mm. black-and-white is accomplished in a specially constructed optical printer in which a Bell & Howell movement is modified to take the 16-mm. film, and the aperture is opened on the edge-numbered side to include the full edge figures. The image is projected through a 3-in. copying lens to the modified aperture of a Mitchell camera which gives a picture size of approximately 0.600×0.825 in., comparable to the sound-film projector aperture. The edge-numbers are approximately in the position of the normal sound-track, and, of course, are not projected. The Hanovia-type AH-4 mercury sodium lamp is used as a printing light, and the 35-mm. negative is produced on Eastman Background X negative stock and developed to a gamma of 0.6. Subsequent prints are remarkably free from graininess and possess a very high fidelity to the original Kodachrome pictures, having been mistaken, at times, for *original* black-and-white productions.

Kodachrome Background Projection Slides for Professional 35-mm. Motion Picture Production

According to B. H. Thompson (16), research engineer of Paramount Pictures Inc., Hollywood, the technique of transferring a Kodachrome image-carrying emulsion from the film to a lantern-plate is as follows:

With the adoption of the high-intensity arc system used in stereopticon machines in the motion picture industry for background projection purposes, the use of straight Kodachrome was rendered im-

possible. It was also impracticable to use Kodachrome cemented to a single piece of lantern-slide glass. As the demand for natural-colour, still-background transparency plates increased, an early solution to the problem was urgently needed. After an inspection of the plates exposed to the heat of the light system in the stereopticon, it was found that the principal difficulty was being encountered not in the breakdown of the Kodachrome emulsion, but in the disintegration of the acetate butyrate film base. The elimination of this plastic therefore was imperative. After lengthy research, including tests and varying processes, the following procedure was adopted as a standard.

Place a clean lantern-slide plate into position on a special plate holder. Next, place the Kodachrome, previously cut to size, emulsion side down, upon the lantern-slide and affix one edge of the Kodachrome to the plate holder with the use of transparent Scotch tape. Then fold the Kodachrome back, using the Scotch tape as a hinge, and with the use of a medicine dropper place a bead of previously prepared 5 per cent. water solution gelatine on the lantern-slide at the edge where the Kodachrome has been attached to the plate holder. Starting where cement has been applied, and with the use of either a squeegee or a roller, press the Kodachrome down upon the glass, maintaining a bead of cement at all times as the lamination is completed over the entire plate area. No great pressure is required in this procedure, but a steady drag of the squeegee or the roller is necessary. Remove the lantern-slide glass from the plate holder and proceed to the second step of the transfer.

With the use of a weak solution of ammonia and water, dampen the gelatine backing of the Kodachrome and allow to stand for several minutes. Then with the use of a razor blade scrape all the gelatine backing from the plastic base. During this stage the film—that is, the acetate butyrate film base—may be damaged, but as this will be removed later it will not affect the finished article. After all gelatine has been removed, place the lantern slide in a Petri dish partially filled with menthol cellusolve acetate, allow to stand for approximately 4 minutes, remove, shake off the excess, and allow to stand for another 30 minutes.

With the aid of a razor blade under one corner, lift off the swollen plastic. It will be found that the plastic has sufficient strength and will separate from the emulsion readily. If the plastic film is too tender, allow it to stand until strength has returned. This will range from 5 to 20 minutes. After the base has been removed, take a small piece of cotton, well saturated with menthol cellusolve acetate, and swab the surface of the Kodachrome emulsion to remove all excess plastic. This may require five or six clean applications, or until the surface is perfectly smooth and glossy. The plate is then ready for use in the stereopticon.

Another way to remove the acetate butyrate film base, which was standard before the adoption of the menthol cellusolve acetate solvent, is by the use of acetone. The procedure up to the time of the immersion of the plate in menthol cellusolve acetate is the same, but at that point the plate is placed in a desiccator and allowed to stand for approximately 24 hours, or until the Kodachrome emulsion layer is dry. The plate is then removed from the desiccator and placed in a Petri dish containing acetone, and with the use of a camel's-hair brush the film base is dissolved by gentle agitation. Several applications of clean acetone are used to ensure the complete removal of the acetate butyrate plastic. No further treatment to the plate is required for its use.

CERTAIN EASTMAN KODAK MULTILAYER PATENTS

E.P. 327,714	E.P. 454,622	E.P. 496,196	E.P. 503,752
E.P. 333,902	E.P. 455,128	E.P. 496,245	E.P. 503,814
E.P. 356,308	E.P. 456,279	E.P. 498,869	E.P. 503,815
E.P. 376,838	E.P. 458,664	E.P. 498,800	E.P. 503,816
E.P. 376,795	E.P. 458,665	E.P. 498,871	E.P. 503,817
E.P. 427,472	E.P. 462,140	E.P. 498,874	E.P. 503,818
E.P. 427,516	E.P. 467,614	E.P. 498,875	E.P. 503,819
E.P. 427,517	E.P. 468,560	E.P. 499,185	E.P. 503,820
E.P. 427,518	E.P. 474,353	E.P. 500,716	E.P. 503,821
E.P. 427,519	E.P. 475,784	E.P. 500,717	E.P. 503,822
E.P. 427,520	E.P. 475,786	E.P. 500,718	E.P. 503,823
E.P. 437,520	E.P. 477,524	E.P. 500,719	E.P. 503,824
E.P. 440,032	E.P. 478,933	E.P. 500,720	E.P. 503,825
E.P. 440,089	E.P. 478,934	E.P. 500,721	E.P. 503,826
E.P. 441,325	E.P. 478,942	E.P. 500,793	E.P. 503,827
E.P. 444,198	E.P. 478,983	E.P. 500,794	E.P. 503,845
E.P. 446,234	E.P. 478,984	E.P. 500,795	E.P. 503,939
E.P. 446,752	E.P. 478,985	E.P. 500,796	E.P. 503,940
E.P. 447,092	E.P. 478,986	E.P. 500,826	E.P. 503,941
E.P. 447,748	E.P. 478,989	E.P. 501,000	
E.P. 451,699	E.P. 478,990	E.P. 501,001	
E.P. 453,233	E.P. 478,991	E.P. 501,002	
E.P. 454,498	E.P. 489,185	E.P. 501,003	
E.P. 454,499	E.P. 493,592	E.P. 501,040	

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Journ. Soc. Mot. Pic. Eng., **25**, No. 1 (July 1935), p. 65.
Kinematograph Weekly (London) (Aug. 1, 1935), p. 32.
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The Technicolor Process

(Technicolor Motion Picture Corporation, U.S.A.; Technicolor Limited, London, England.)

Introduction.—Long after the colour film has been superseded by some wonderful electronic device the magic word **TECHNICOLOR** will survive. Novelists write of "sunsets in gorgeous technicolor," and fashion journals report a *tout ensemble* as "gown in monochrome and hat in technicolor." Indeed Dr. Herbert Kalmus and his associates enriched the language on that day in Boston when they invented the great name, honouring their *alma mater* the Massachusetts Institute of Technology, in so doing. To-day a colour film is a Technicolor film, as far as the press is concerned, no matter what the process may be.

This famous process owes more to engineers than to chemists, seeing that to work it successfully nothing new to photography had to be made, all its elements were ready to hand, nothing new had to be invented that was not mechanical, or that was more than refinement upon existing practice. Its sponsors were faced with innumerable problems, some of great complexity, but in nearly every case precision engineering provided the answer. Why was this? Because the film was printed not by the action of light upon a sensitive substance but by the mechanical transfer of dye from a matrix in relief—a true type of printing.

Dr. Kalmus and his co-workers, D. F. Comstock, W. A. Westcott, L. T. Troland and others, began their adventure by succumbing to the seductions of optics in the form of the additive process, but they very

soon realized their error and relegated their registering projection lens to the museum, where the devices of others who have trodden this primrose path also properly belong. At this stage they must have considered many alternatives. They must have reviewed the whole history of colour photography and having made only one other false start, in which they attempted, with little success, to cement together a pair of dyed reliefs, they resuscitated the inventions of L. Warneke, who discovered the wash-off relief process (1881) and E. Edwards, an Englishman, who invented "Hydrotypes" or "Imbibition printing" (1875), and henceforward never diverged from the path they had chosen. How well they chose the next few years were destined to prove, yet at that time (1927-28) imbibition can hardly have seemed promising when the microscopic dimensions of the cine frame are considered, for it must have seemed certain that there would be present the defect of unsharp contours due to lateral diffusion or "bleeding" of the dye, a fault peculiar to imbibition which had invariably been experienced.

Before describing in any detail the technique of this process it is helpful to analyse the complex of problems for which solutions had to be found. These may be classified thus:—

- (a) Means for obtaining accurately registered separation negatives, either for two-colour or three-colour analysis.
- (b) Means for making positive relief matrices from the separation negatives.
- (c) Discovery of suitable dyes for imbibition.
- (d) Means for mechanically registering a succession of matrix films to the film destined to bear the combined dye-transfer images.
- (e) Means for printing a silver sound track including, if required, a silver key picture image.
- (f) Determination of chemical formulæ and optimum physical and chemical conditions.

Technicolor is *one*, but *one* only, successful solution of this very complex problem. In the existing state of knowledge other equally successful solutions could have been devised. Why was this not attempted? The answer is that competing investigators were effectually scared away by rumours as to the magnitude of the task and the size of the investment necessary. Nobody dared to tackle the job again. Yet there was nothing to forbid others from scaling the same peak by another route. However, once the original adventurers had got to the top of the mountain they remained in solitary possession. And there on the summit they still are, triumphantly in possession not of unassailable patents, but of an equally unassailable "know-how."

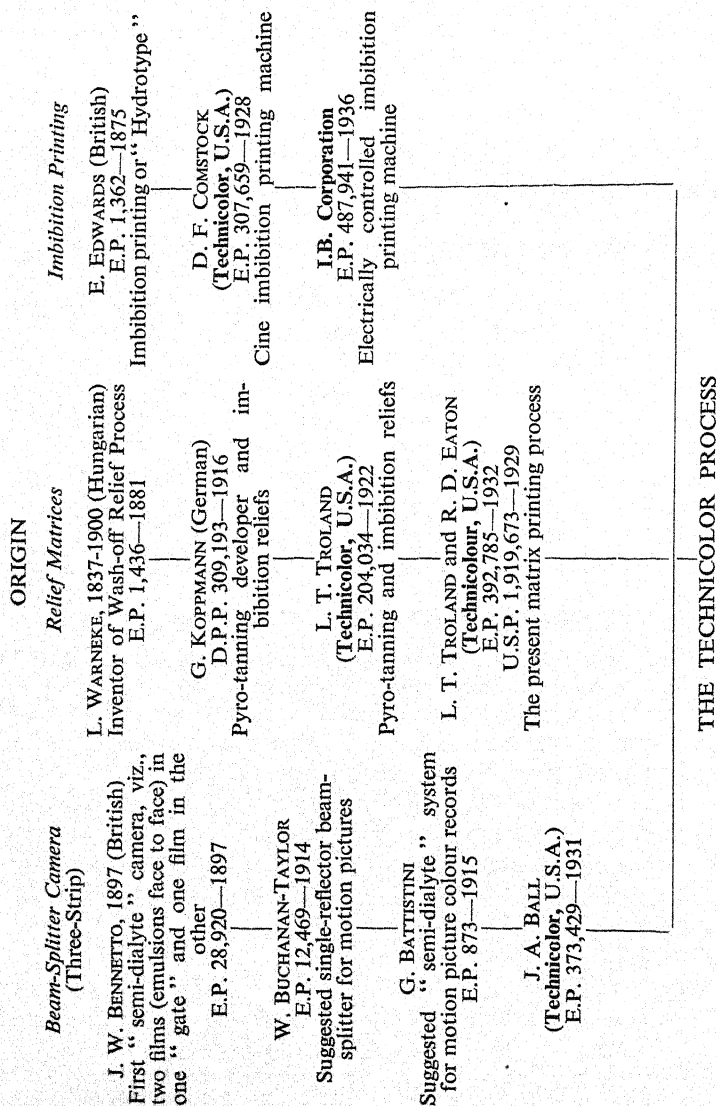
The early essays in the additive process had built up a background of experience in the design of beam-splitters which predisposed these men to the adoption of a special camera in preference to bipack; at this

period only two-colour was under consideration. Once again their debt to early pioneers must be acknowledged since the system they adopted had been invented years before by an Englishman, J. W. Bennetto (1897). This inventor describes the present three-strip arrangement, namely two films face to face in one focal plane and a single film in a focal plane at right angles provided by a reflector at 45° to the axis of the objective lens. The reflector is a prism block consisting of two 45° prisms cemented together to form a cube, one of the 45° faces being coated with a partially reflecting surface of metal (aluminium, gold, silver, etc.).

Once imbibition had been chosen as the method of printing there were a number of alternatives. The technique of "Pinatype" was well known. This invention of the Frenchman, Leon Didier, in 1903, had been developed by the Germans, and had been shown to be capable of making fairly good dye-transfer prints (F.P. 337,054—1903, etc.). It was always difficult to get clean whites because the master is not a relief at all but a surface of gelatine varying in hardness, and the hardened areas took up the dyes which had an affinity for hardened gelatine and the unhardened areas were washed free of dye. Then there was the possibility of using bichromated gelatine, the exposed areas of which are hardened by the action of ultra-violet light, a relief being easily produced by exposing through the support and washing away the unhardened gelatine in warm water (as in the "carbon" process). But exposure is lengthy and requires powerful sources of ultra-violet light. Of the various alternatives, that invented by L. Warneke (1881) seemed to fulfil most of the requirements, in which advantage is taken of the tanning action of the developer pyro. Indeed the first Technicolor formulæ cited in the Troland patent (E.P. 204,034) in 1922 differ negligibly from Warneke. Thereafter refinements seek retention of the thinnest steps of the relief, the preservation of detail and the control of contrast. From this period onwards surely much of the credit belongs to Eastman Kodak, who from the beginning made the matrix film for the Technicolor organization. The material closely resembled the Jos-Pé film which had been since 1916 popular in Germany for making paper prints by the dye-transfer process, utilizing pyro-tanned wash-off relief films made in accordance with the patents of G. Koppmann (D.R.P. 309,193—1916, etc.).

But the heart of the Technicolor "set-up" lay not in these photographic problems, which had been largely solved in advance, but in mastering the prodigious difficulty of bringing three reliefs successively into contact with the image-bearing film at identically the same point. And here we can appreciate the marvellous accuracy of film perforation since only by means of these perforations could this form of printing have become possible. To Bell and Howell goes the credit for precision perforation.

The student should pay particular attention to the patents of the I.B. Corporation of Cambridge, Massachusetts. Quite obviously this firm has played an important part in the history of Technicolor, as witness key patents such as E.P. 487,941 dealing with the imbibition machine.



Important contributors also were, E. A. Weaver, E. J. Wall, B. Sugden, B. S. Tuttle, J. F. Kienninger, H. N. Cox, A. B. Clark, W. Webb, M. G. Young, F. E. Wing, F. C. Atwood, J. M. Andrews, R. D. Eaton.

Technicolor is thus the famous descendant of a most respectable ancestry. The story of its birth and origin generally begins with the youthful partnership of three undergraduates of the Massachusetts Institute of Technology, Dr. Herbert Kalmus, Daniel Frost Comstock and W. A. Westcott. They gave us:—

1. A beam-splitter camera. (Three-strip Negatives.)
2. A gelatine wash-off relief. (Matrices.)
3. Dye-transfer printing. (Imbibition.)

But to give credit where credit is due, these three items were the re-incarnation of ideas first conceived respectively by:—

1. J. W. Bennetto, 1897. (First semi-dialyte camera.)
2. L. Warneke, 1881. (Wash-off reliefs by tanning developer.)
3. E. Edwards, 1875. (Dye transfer printing or "hydrotype.")

These are the indubitable ancestors of Technicolor but at present they seem to occupy rather obscure niches in our motion-picture Hall of Fame.

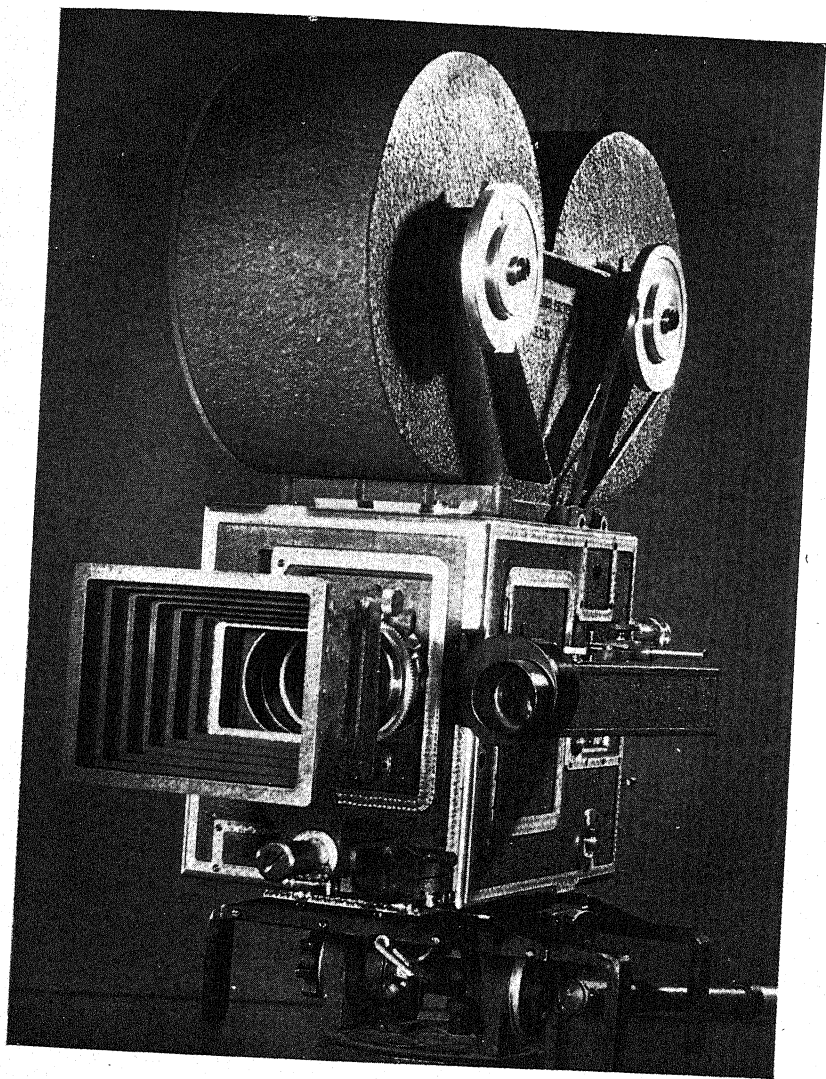
Brief History

Founded by Kalmus, Comstock, and Westcott. Consulting Engineers, Boston, Mass., U.S.A.

First Laboratory 1916-1917	A railway car, equipped with chemical laboratory, darkroom, fire-proof safes, power plant and offices. Services included sensitizing, perforating, processing negative, conditioned air, examination of film and making control measurements and tests.
First Production	"The Gulf Between" with Grace Darmond and Niles Welch. It was financed by Technicolor.
Camera	Single lens. Prism Divider. Pair of images of <i>normal</i> dimensions (viz., Silent frame).
Projection	Double aperture with filters inserted. Adjustment of register with glass wedge. Special arc and projection optical system. Kalmus writes, "I decided that such special attachments on the projector required an operator who was a cross between a college professor and an acrobat."
1918	Dr. Leonard T. Troland patented fundamental monopack claims.
1919-1921	Process attempted of cementing pairs of dyed gelatine reliefs. Original beam-splitter used for the negative records.
1921	Pilot Plant built in Brookline Avenue, Boston.

COLOUR CINEMATOGRAPHY

1922	Technicolor produced "Toll of the Sea" (Metro). Insufficient laboratory capacity prevented prints from being delivered until following year. Price 27 cents a foot. Producers declared 8 cents limit.
1923	New plant erected in Boston. Capacity 1,000,000 ft. monthly. Small laboratory unit founded in Hollywood. Paramount made "Wanderers of the Wasteland." One hundred and seventy-five made at 15 cents per foot.
1924	"The Black Pirate," being cemented pairs of relief films, trouble was experienced in projection (Cupping).
1926	Up to this date \$2,500,000 had been spent. Twelve two-reelers were sanctioned for production by Technicolor.
1928	The imbibition process adopted. Two-colour imbibition with silver track. Warner's produced first all-talking Technicolor picture "On With the Show."
1929	Hollywood plant capacity doubled.
1930	Contracts for 36 feature-length. Twelve million feet of negative required and 60,000,000 feet of positive. Technicolor appropriated 3,000,000 dollars for plant, equipment and research.
1931	Serious effects felt of depression. 1,200 employees dropped to 230.
1932-1933	First three-strip beam-splitter camera completed and three-colour imbibition perfected. Walt Disney made "Flowers and Trees," the first three-colour production. Exclusive three year contract signed with Disney. Basic price for prints 5 cents per foot. Merian Cooper and John Hay Whitney financed "La Cucaracha," first three-component studio job. Closing sequences made for "The House of Rothschild" and "Kid Millions."
1935-1936	"Becky Sharp" released by Pioneer Pictures. First feature three-colour production. Walter Wanger's "Trail of the Lonesome Pine" with exteriors followed. Plant now making 2,750,000 feet of prints a month. "Wings of the Morning," first feature produced in England with Ray Rennahan as Director of Photography. Processed in the Hollywood plant.
1936	Technicolor Limited formed to build British laboratory at West Drayton. By this date some 23 cameras had been built, costing \$25,000 each.
1937	Disney made his first cartoon feature, "Snow White and the Seven Dwarfs."



(By courtesy of Technicolor Ltd.)

FIG. 244.—The Technicolor beam-splitter "three-strip" camera.

(Facing p. 456)

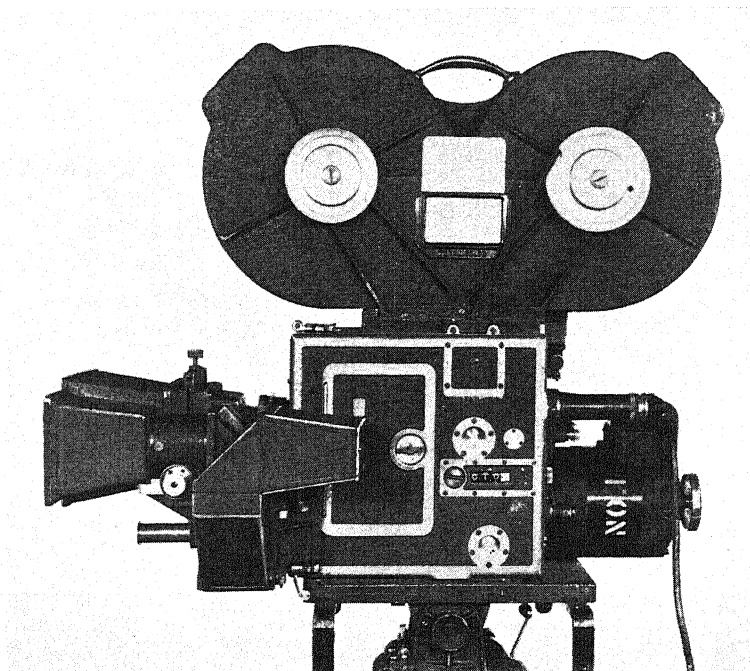


FIG. 244A.—The Technicolor beam-splitter “ three-strip ” camera—side view.

1939	Further laboratory extensions opened in Hollywood.
1942	Monopack (Kodachrome modified) used for first time for the exteriors only in a major studio production, M.G.M.'s "Lassie Come Home."
1944	Monopack first used for a full feature in 20th Century-Fox production "Thunderhead."
1946	Technicolor delivered 165,027,297 feet of positive print, covering 33 American and 5 British features in addition to large numbers of short subjects.
1949	1,000,000 feet processed per day.

Classification.—Subtractive process. Two- or three-colour dye-transfer printing by successive imbibitions from wash-off gelatine relief matrices. Registration effected by travelling pin-belt. Film base is coated on one side with a positive emulsion which is used for printing the sound track, picture key, and frame surrounds. The dyes are transferred subsequent to the completion of the silver print.

Camera.—Beam-splitter incorporating a prism block consisting of two 45° prisms cemented together to form a cube, one of the 45° faces being coated with a partially reflecting surface of gold. The prism diverts part of the beam originating from the lens to a gate at 90° to the lens axis, the balance of the beam passing through the prism to a gate in the normal position (E.P. 398,339, E.P. 492,673) (Fig. 244A).

(a) *Three-strip Film Arrangement.*—Bipack records the diverted beam. Single film records the direct beam. The bipack consists of a blue-recording front film, the emulsion surface of which is coated with a red filter excluding green and blue light from the rear film, which being coated with a red sensitive emulsion records red light only. The single film bears a green sensitive emulsion. This bipack and single film, known as "Three-Strip" is manufactured by Eastman Kodak.

(b) *Successive Frame Negative.*—Alternatively to the three-strip system, separation negatives may be recorded on a single film in the form of successive sets of blue, red, and green filter records. Since each projection positive frame requires three successively exposed negatives, time and space parallax must prohibit the photography by this method of moving subject matter. The method is therefore employed for the photography of still subject matter such as animated drawings, titles, or trick films of any description.

(c) *"Monopack."*—Use is also made of a multilayer colour film made by Eastman Kodak, which is probably very similar, if not identical, to Kodachrome. From this positive colour film (see Kodachrome) either 16-mm. or 35-mm. separation negatives are extracted by optical

printing technique. From these separation negatives positive printing relief matrices can be printed by a suitable skipping optical printer.¹

Projection.—Normal. *Sound Track.*—Normal, silver.

Technicolor Lenses.—These were fully described by H. W. Lee, formerly of Taylor, Taylor & Hobson Ltd., in *Nature*, by the kind permission of the editor of which the following section is reprinted.

In colour photography it is necessary to analyse the light reflected by coloured objects into at least three spectral regions which, where there are three only, may be termed red, green, and blue respectively. This is done by means of colour filters which transmit definite portions of the spectrum and absorb the rest; the three negatives are produced either successively or simultaneously. In cinematography the negatives must, of course, be made simultaneously unless the rate of movement of the film is increased threefold, to which there are grave objections. The three negatives may be made simultaneously by means of three lenses; this results in colour parallax, and the three images will never exactly superpose. Alternatively, the beam of light issuing from a single objective must be divided. This division may be made by means of superposed filters, the components of white light being successively subtracted and acting on sensitized films superposed. The objections to this are that the films and filters must be very thin if the composite tripack and filter film is not to be too thick, and that each layer of emulsion produces a certain amount of scattering, so that the successive images are more and more diffused. Other methods of dividing the beam are by successive reflections from thin, partly reflecting and partly transmitting films, which may be either isolated films of collodion or films of silver on glass surfaces. The silver may be in the form of totally reflecting films partly covering the surfaces on which they are deposited, a method not without objection, since the areas of film must be small if there is not to be differentiation between different parts of the light beams; alternatively, the silver films may be so thin as both to reflect and transmit. The Technicolor process is, optically speaking, a combination of two processes suggested above. *One* semi-reflecting metallic film on the diagonal plane of a glass cube is combined with a bipack, to which the objections of the tripack do not altogether apply, as the two sensitive films can be placed in contact.

The glass cube placed between the lens and the film has considerable thickness (being approximately equal to the size of field covered) and therefore produces considerable aberration. This fact was not sufficiently realized by early experimenters in colour photography, who tried to combine prism "beam-splitters" with normal lenses on the market, which, of course, had not been computed for use with considerable thicknesses of glass. The result was poor definition and images

¹ In 1938 Dr. Kalmus said: "I predict that within two years Technicolor will have done away with special cameras." Yet a number of new beam-splitter cameras are in course of construction (1949).

of unequal sizes. Technicolor, however, early realized the necessity for taking the prism into account in the design of the lens system, and in 1918 D. F. Comstock took out a patent (B.P. 131,422) for several constructions, having apertures up to $f/3.9$, for lens systems combined with prisms. In 1927, however, their prism system was simplified and the need felt for the lenses of larger aperture, owing to the change in cinema technique from outdoor to studio photography. Technicolor approached Taylor, Taylor & Hobson Ltd., who were making lenses having an aperture of $f/2$, and asked them to design a special lens for their needs. This was for two-colour work. With the change to three-colour work in 1931, a further change was needed, and, moreover, the matter of colour correction became more stringent.

It is possible to equalize the focusing position and the focal lengths for two parts of the spectrum which would, in practice, be the "centres of gravity" of the spectrum bands passed by the two filters used, but when three colours are in question there is the difficulty that the third colour must necessarily be out of focus owing to the so-called "secondary spectrum." This secondary spectrum can be reduced in certain optical systems such as telescopic objectives and photographic lenses of small aperture by the aid of special glasses; but the dispersive power of these glasses, the so-called "telescopic flints," which have partial dispersions more nearly proportional to those of crown glasses than the flints in ordinary use, is so low that, in photographic systems of large aperture and considerable field dependent entirely upon these glasses, the construction is prohibitively complicated. However, since, in the new Technicolor process, only two images are formed in a plane at right angles thereto, it is possible to allow for the slightly different focus for the green, if the foci for the red and blue coincide. These, then, were the conditions to be fulfilled: the red and blue foci must coincide, the tolerance being that the blue focus might be 0.0005 in. longer than the red, as the blue negative is the rear one of the bipack. The green focus could be 0.003 in. shorter than the common focus for the blue and red. These conditions were for the "standard" focal length of 50 mm. The aperture required was $f/1.7$. As there is inevitably some loss of definition in colour processing, the definition of the lenses was to be better than that of lenses for non-colour work. Other lenses of focal length 70 mm., 100 mm., and 140 mm. were also required.

Now the secondary spectrum, which required an adjustment of 0.003 in. for the green on the 50-mm. lens, increases with focal length, so that it becomes 0.008 in. with the 140-mm. lens, while the "adjustment," being made on the camera, is fixed. It thus became necessary to reduce the secondary spectrum with the longer focus lenses. Fortunately, the Parsons Optical Glass Co. (now Chance-Parsons) came to the rescue with a new glass; an experimental melting

produced a glass having a reduced secondary spectrum and having the low V of 44.9 (as against 52.2 in the old "telescopic flint"). By judicious incorporation of this glass in one or two components in the longer-focus lenses, these were designed to give approximately the same difference between the green focus and red-blue focus as in the standard lens.

A further interesting problem arose when short-focus lenses were required, because, with normal types, there is not sufficient clearance between the lens and the focal plane to accommodate the prism.

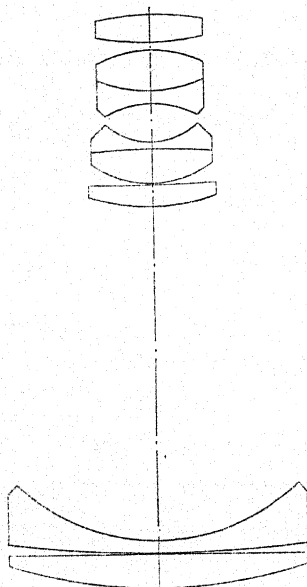


FIG. 245.

Mr. J. A. Ball of Technicolor had tried placing a negative lens in front of an ordinary cinematograph-taking lens, the distance between the two being greater than the focal length of the positive lens; thereby he decreased the focal length and at the same time displaced the nodal plane towards the focal plane, giving greater clearance.

A negative lens so placed, however, introduces considerable barrel distortion. Ball reduced this by using two negative components, each a cemented doublet, but when the problem was put to Taylor, Taylor & Hobson Ltd. to provide a lens of aperture $f/2$ free from distortion, a complete solution was forthcoming with a negative consisting of only two simple elements. Fig. 245 shows the Taylor-Hobson lens. The same stringency as to colour correction, of course, applies to this lens (E.P. 355,452).

The closeness of the limits for colour correction necessitates special precautions in manufacture. In a batch of lenses made to very close tolerances of radius and thickness and made from identical glass melts, it is rare to find the chromatic corrections identical to the Technicolor specification, owing to small variations in the composition of glass throughout the pot. The assembled lenses are first tested for focus throughout the spectrum on a collimator illuminated through a constant deviation prism. If necessary, alterations are then made to bring the chromatic corrections right. Finally, a photographic check is made. An inclined object consisting of parallel lines is photographed through the actual colour filters used by Technicolor.

The Technicolor arrangement of films is a derivative of the semi-dialyte system of J. W. Bennetto (E.P. 28,920, 1897). The optical system is the work of Messrs. Taylor, Taylor, Hobson & Cooke Ltd., of Leicester, England.

RECENT CAMERA PATENTS

E.P. 480,173. Technicolor Motion Picture Corporation.

An oscillating film gate causing the film to engage alternately a claw feed mechanism and fixed registration pins. In fact, the familiar "shuttle gate," and similar to the famous Bell-Howell Type I gate. This movement provides the ideal conditions for registration accuracy by virtue mainly of the fixed registration pins.

E.P. 537,802. Technicolor Motion Picture Corporation.

Optical defects due to imperfect contact of bipack in the camera gate have always presented an annoying snag. In this patent the two films are separated by a pin (presumably recessed) just before they enter the gate, the idea being to feed the two films along a gradually converging path in order to exclude air-pockets by progressively squeezing out the air on the approach of the two films to the gate. Means are also provided for lubricating the films with a light mineral oil. This is done by oil-saturated pads between which the films run obliquely immediately before they are separated by the pin above mentioned. The use of oil for such lubrication would seem to invite trouble arising from spread of oil over image areas on the film (Fig. 246).

E.P. 538,080.

A view finder control device for cameras having an axially and laterally adjustable optical view finder system and a confined housing characterized in that the mechanism for adjustment of the optical system moves with the latter whereas as the control means for the said mechanism is mounted on the housing, and the adjusting mechanism and the control means are connected by an articulated link transmitting motion there between.

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E.P. 538,744.

Parallax compensating focusing view finder, and arrangement to conform to different lens foci.

E.P. 539,228. Technicolor Motion Picture Corporation.

This invention combines the advantages of the Technicolor beam-splitter with those of multilayer film. A bilayer film is placed in one

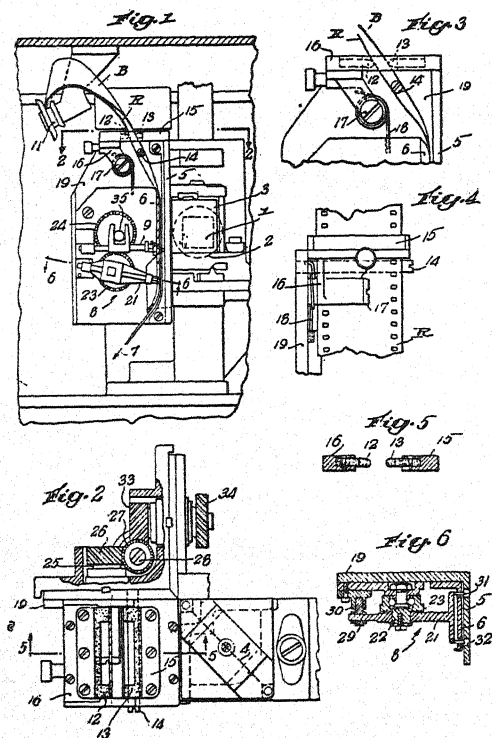


FIG. 246.—E.P. 537,802 of Technicolor.

gate and a monolayer in the other. The bilayer film records blue light on the outer emulsion layer and red on the inner. Needless to say, a destroyable yellow filter divides the two emulsions. The monolayer film records green light. The bilayer film is processed to a reversed positive and colour developed to yellow-cyan. The monolayer film is similarly reversed and colour developed magenta. From the bilayer film the blue and red separation negatives are extracted, and from the monolayer the green separation. Clearly, imbibition matrices can then be made as usual. The method should offer important advantages, as for example;

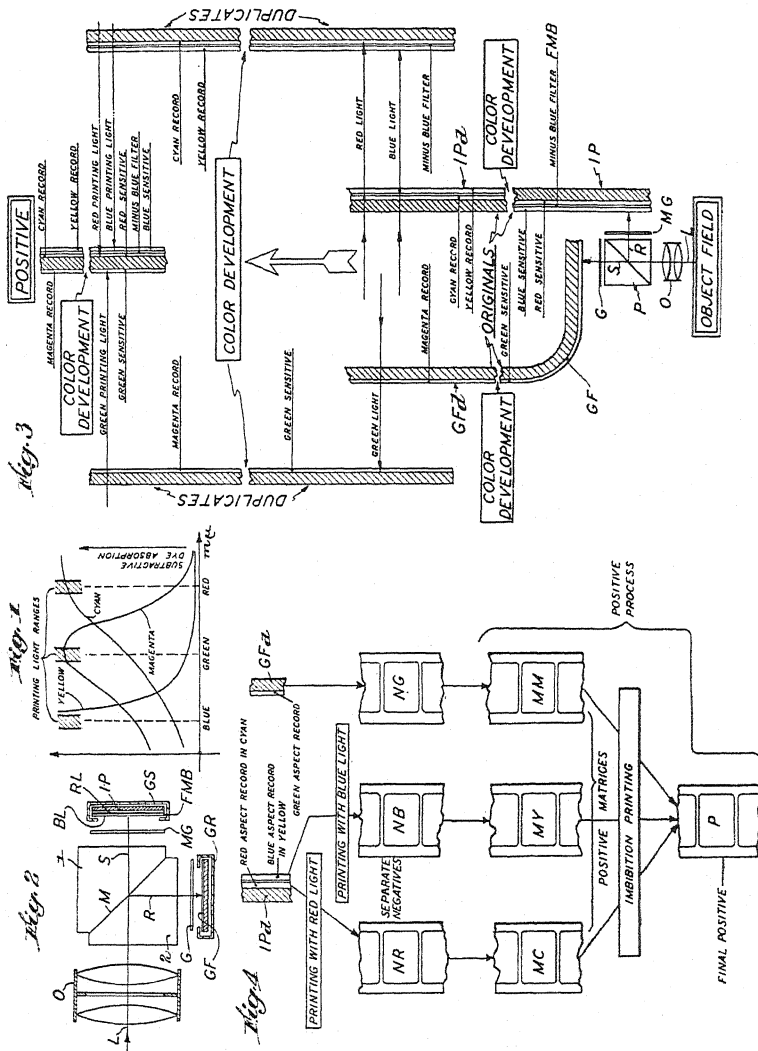


FIG. 247.—E.P. 539,228 of Technicolor.



1. The elimination of bipack, which any cameraman would count a blessing.
2. Avoidance of the common absorptances of the subtractive dyes in a trilayer material which are the origin of faulty colour separation.

To quote the patent: "It is practically impossible to separate, without considerable falsification, colour aspects recorded in the subtractive ranges yellow (minus blue), magenta (minus green), and cyan (minus red), by printing with light absorbed by the respective subtractive records." As indicated in Fig. 247, the absorption ranges of subtractive printing matters overlap considerably. Therefore, if, for example, the yellow record—superimposed on magenta and cyan records—is copied with blue light, the magenta record and the cyan record contribute undesired density patterns, since they likewise pick up a certain amount of the cyan record densities, whereas the red light provides a comparatively pure copy of the cyan record. Accordingly, one of the offending cyan and magenta records—for example, the magenta-coloured record of the green aspect—is taken separately, and can therefore be printed without introducing falsifying components in the other two records. It will be evident from Fig. 247 that, for example, the removal of the magenta record merely leaves a contamination of the yellow copy, which is rather slight and, moreover, of secondary importance, due to the fact that the yellow record does not materially contribute to definition and gradation of the completed picture.

Evidently prints can equally well be made on trilayer film coated two layers on one side and one layer on the other, or coated in the conventional way as in Kodachrome and Ansco, all three layers on one side. The notion is well adapted to the making of good duplicates.

Processing of Negative and Printing of Matrix

Negative Development.—Technicolor negatives are developed to a gamma of 0.65 in D-76. The negatives are drum developed in 1,000-ft. lengths.

Before development the blue record negative is treated in a bleaching bath to destroy the red filter coating on the surface of the emulsion. A solution of hydrosulphite may be used.

Matrix Printers

Material.—Eastman orange-dyed emulsion No. 1514 on $7\frac{1}{2}$ /1,000 in. film base.

Printing.—Exposed through base with tungsten filament source used with an ultra-violet filter plus a No. 39 Wratten Filter. Alternatively

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blue filters of varying density may be used to control contrast. After exposure the matrix film is given a flash fog to threshold value with light identical to that used for printing the image. An ultra-violet absorbing filter is inserted between the light source and the film.

Processing

TIME-TABLE (TEMP.)

Step.	Description.	Time in Minutes.
1	Development	3
2	Wash	2
3	Oxidizing Bath	5
4	Hot Water Etch (Relief development) ..	3-4
5	Fixation	3
6	Wash	5
7	Dry	

MATRIX DEVELOPMENT FORMULA (E.P. 392,785)

Developer

Pyro	8.0 gm.
Citric Acid	0.2 "
Pot. Bromide	1.5 "
Sodium Hydroxide	3.0 "
Ammonium Chloride	1.5 "
Water to	1,000 c.c.

Time: 3 minutes
Temp.: 64° F.

Wash.

H₂O/pH 6.5

Time: 2 minutes

Oxidizing Bath.

Potassium Ferricyanide	14 per cent.
Time: 5 minutes	
Temp.: 65° F.	
pH: 3.7	

Hot Water Etch.

H₂O

Time: 3 minutes
Temp.: 130° F.

FIXATION

Hypo 10 per cent.
Time: 3 minutes

PRINTING

KEY IMAGE OR " BLANK " BLACK-AND-WHITE SILVER PRINT

In the Technicolor process the film upon which the dye transfers are made is a normal black-and-white positive film bearing a completed silver image sound track, a lightly printed picture key,¹ and frame surrounds.

PROCEDURE

Colour separation negative used for printing picture image	The Green negative record (Magenta printer)
Film stock employed	Eastman Motion Picture Release Positive
Development formula	Modified D.16 (see below)
Gamma	2.15

MODIFIED D.16 FORMULA (DEVELOPMENT OF BLACK-AND-WHITE " BLANK ")

Metol	1.8 gm.
Hydroquinone	36 gm.
Sodium Sulphite (anhyd.)	240 gm.
Sodium Carbonate (mono)	122 gm.
Potassium Bromide	5.4 gm.
Citric Acid	4.2 gm.
Potassium Metabisulphite	9 gm.
Water to make	6 litres

NOTE.—The 7th Step of the wedge exposed on the Type IIB Eastman Sensitometer must have a density of .64.

After fixation the " blank " is hardened in a chrome alum bath. The time is critical in relation to the time during which the " blank " can be kept prior to dye imbibition (normally 24 hours). Too short a " chrome wash " will cause the emulsion of the " blank " to be too soft which gives rise to bleeding of the dyes during transfer. Too long a " chrome wash " will cause incomplete transfer of the dyes from the matrix due to small particles of air being trapped between the matrix and the " blank." In extreme cases there may be general failure to transfer the whole of the dye with consequent false colour balance in the print.

If a " blank " is to be kept for a period in excess of 24 hours the chrome alum wash must be shortened in time, owing to the fact that a " blank " tends to harden with keeping. Should a " blank " have become excessively hard owing to circumstances delaying transfer it can be run through the developing machine again with a chrome alum wash suited to the new expected time-lapse between chrome wash and transfer.

The time of development of the sound track printed on the " blank " is invariably the same, whether the track be of the variable area or variable density type. Since the sound track is developed independently

¹ Said now to be omitted, but in 1938 Dr. H. Kalmus said, " The present system is really four-component " (7).

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of any considerations of the characteristics of the picture image the conditions for ideal processing are present.

DYE TRANSFER (IMBIBITION)

Order of transfer	Yellow, cyan, magenta
Dye baths	Agitated by compressed air at the rate of 372 c.c. per minute
Temperature	90° F.-101° F.
Immersion period ..	2 minutes

Surplus dye washed off—20 seconds at 70°-100° F.

Surplus water is blown off and the semi-dry matrix is then “ married ” to the “ blank ” *under de-aerated water*, the blank having been previously pre-wetted for 30 seconds at 65° F. in de-aerated water (see E.P. 487,941).

By means of copper water-jacketed runways the mono-metal register-pin travelling band is kept at such a temperature that the film sandwich is kept heated during the transfer.

<i>Time of Transfer.</i>	<i>Colour.</i>	<i>Temperature (°F.).</i>
2 minutes	Yellow	100
2 ”	Cyan	130
2 ”	Magenta	130

Removal of Surplus Dye (known as “ Dechro,” viz., Sodium Carbonate, 10%).

Rinse.—2 minutes.

Blow off with compressed air.

Dry.

DYE BATH FORMULÆ*

Yellow.

Chlorazol Brilliant Yellow 3G. 200	.. ..	2 gm.
Chlorazol Fast Orange ER. 180	.. ..	0.25 gm.
Acetic Acid 28 per cent.	.. ..	10 c.c.
Water to make	.. ..	1,000 ”

Cyan.

Disulphine Green B. 150	.. ..	0.25 gm.
Solway Celestol B. 250	.. ..	1.25 ”
Lissamine Green B. 200	.. ..	0.40 ”
Acetic Acid 28 per cent.	.. ..	30 c.c.
Water to make	.. ..	1,000 ”

Magenta.

Chlorazol Fast Pink BK. 180	.. ..	3.6 gm.
Chlorazol Fast Red BK. 170	.. ..	0.45 ”
Benzo Violet R	.. ..	0.5 ”
Acetic Acid 28 per cent.	.. ..	50 c.c.
Water to make	.. ..	1,000 ”

* These data are schematic only and no reliance can be placed upon any exact correspondence with present practice.

BRITISH AND AMERICAN TECHNICOLOR DYE EQUIVALENTS

<i>British.</i>	<i>American.</i>
Disulphine Green B. 150	Fast Acid Green B.
Solway Celestol B. 250	Anthraquinone Blue AB.
Chlorazol Fast Red K. 170	Paranol DF. Red 8 BL.
Chlorazol Fast Pink BK. 180	Amidine Fast Rose 2 BL.
Chlorazol Fast Orange ER. 180	Dupont Pontamine Orange ER.
Chlorazol Brilliant Yellow 3G. 200	Dupont Brilliant Paper Yellow Conc.
Lissamine Green B. 200	Pontacyl Green SN.

In B.P. 487,941 of the I.B. Corporation covering certain aspects of the Technicolor imbibition printing machine, the following dyes are mentioned:

Cyan	Erioglaurine (C.I. No. 671)
Magenta	Acid Fuchsin (C.I. No. 692)
Yellow	Resorcine Yellow (C.I. No. 148)

"I.B." Transfer Machine (General Description)

The machinery used today by Technicolor Ltd. consists of two early type dye transfer machines sent to England by Technicolor Corp. to enable the English firm to start output on a reduced scale (20 feet per minute).

Owing to the war, no replacement was feasible and as a result of the increasing demand for colour productions this machine has continued to run practically non-stop (week-ends excluded) ever since. It is now said to be running at the increased rate of 120 feet per minute.

The machine was built by the I.B. Corporation (U.S.A.) and designed by Mr. "Mack" Ames of The Technicolor Motion Picture Corporation (U.S.A.). (See I.B. patent abridgement below.)

The machine is four banked, the fourth not being in use (*i.e.*, Yellow, Cyan and Magenta; in that order). Fig. 248 illustrates schematically the general arrangement of the machine.

The "Blank"

The "blank" is the first stage in the making of a Technicolor print and consists of Kodak 1301 stock (Negative perforated) bearing a silver sound track and picture rebate and in some cases a faint silver picture image known as the "gray" in London, and the "key" in Hollywood.

These blanks are fed on to the machine on the yellow side by means of a continuous feed elevator, a sprocket with a double, normal, and stationary speed, a form of "dog clutch" being fitted between the feed reel and elevator. Each roll of blank is spliced to the preceding one by a normal cement join. The splicing "cue" for synchronizing purposes is printed on the "blank," corresponding to the track negative as edited by the negative cutting department.

The blank then runs from the feed elevator past a mercuroid trip switch (see page 472 on Mercuroid Trip Switches) into the yellow "pre-wet bath" containing "de-aerated" water (see note on "de-aerator"). The yellow, cyan and magenta pre-wet baths are long horizontal troughs each running above its appropriate colour "table."

The object of the pre-wet is partially to soften the surface of the blank emulsion in order to decrease the chance of transfer due to "air" and to increase the receptivity of the emulsion to the transference of dye.

After, say, two minutes' immersion, the blank emerges from the yellow pre-wet, travels past two blow-offs (one either side of the film to remove surplus water), turns downwards past a mercuroid trip switch, and into the "roll tank" (entering it from the top) which is filled with de-aerated water. This water is kept flowing at a rate of 9 gallons per minute.

Marrying Matrix to "Blank"

It is in this roll tank that the blank is "married" or brought into close contact with the yellow matrix, the blank being uppermost. Both are then seated on the monel "pin belt," by means of pressure exerted by four 6-in. diameter rubber treaded rollers; that is, two above and two below the pin belt. A jet of de-aerated water is directed at the point of first contact between blank and matrix. This is another precaution against the possibility of "transfer for air," a defect brought about by the presence of particles of air trapped between matrix and blank, and so causing transfer of the colour in question. This defect is most liable to occur in areas of great colour contrast (*i.e.*, air particles caught in the "shelf" in the "topography" of the matrix surface).

At about the same time as the blank is being fed on to the machine, the appropriate yellow matrix is also being run on to a continuous feed elevator, each roll of matrix being cut to length, for synchronization with the blank, by the matrix make-up department. The matrix is attached to its predecessor by means of a 6-inch length of monel strip (perforated in the same manner as a piece of negative cine film), and by four two-pronged clips.

A driving sprocket with a three-position free wheel, normal, and stationary type of dog clutch, supplies this elevator from the feed reel.

Another sprocket carries the matrix into the top of the dye tank, where it runs in vertical paths past two cascades. These cascades are supplied with dye pumped up from a vat below the floor. The dye is passed through three filter bags, one large one in the vat and two smaller ones over the dye tank cascades. Dye corrections are applied by boosting every 15 minutes under the direct control of the chemical department who are advised partly by "hand transfer tests" of a gray scale, and partly by the viewing room.

During its travel through the dye tank the matrix passes over a

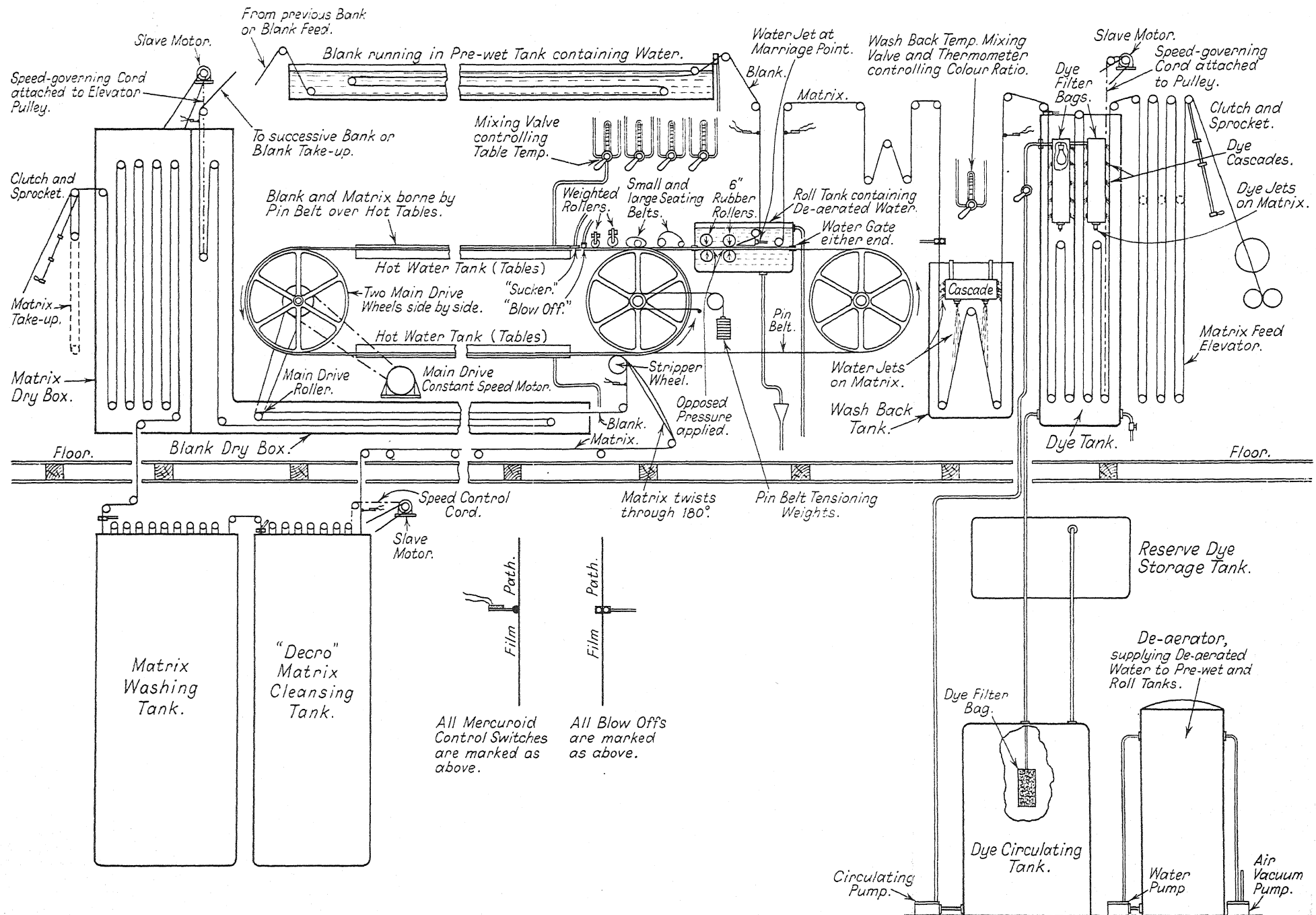


FIG. 248—General arrangement of the "I.B." Transfer Machine used for printing Technicolor positives. (Schematic only.)

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driving sprocket and a weighted jockey pulley attached to a cord. This cord actuates the speed control arm of a four-bush motor which drives this section of the machine. In this way the driving motor speed is governed by the tension of the film.

After leaving the top of the dye tank, the yellow matrix runs down into the "wash back" where it remains for about 90 seconds, travelling in a vertical path past either end of a hot water cascade whose temperature can be easily varied by means of a mixing valve.

The object of the "wash-back" is to wash off the dye superfluous to the amount required to bring about the desired colour ratio. The effectiveness of this washing off is directly related to the temperature of the water used, the duration of the "wash-back" time being constant (*i.e.*, the greater the temperature the greater the wash-off).

It is of interest to note that the main difference between the technique used in the London plant and that used in Hollywood, is that the Americans keep the temperature constant, but control the duration of "wash-back." In either case the technique is directly controlled by the viewing room.

From the "wash-back" the matrix passes through a small elevator, the movable element being heavily weighted. This does no more than supply or take up stock in the event of slight sluggishness of the controlled driving motors when responding.

From this elevator the matrix passes two blow-offs (one either side of the film), runs downwards past a mercuriod trip switch and enters the roll tank from the top, passing under a roller on to the pin belt where the blank is pressed on to it by the first 6-inch roller and held in register by the pins.

The pin belt is 240 feet long, consisting of monel perforated strip 35 mm. wide, with both large and small teeth soldered in these perforations. The small teeth are on the "track" side of the blank. The whole length is soldered into a loop. Four wheels of approximately 40-inches diameter enable it to travel from end to end of the machine four times. The two wheels at the dye tank end (termed the "wet end") are set at a slight angle to each other, to give the desired cross over, and about 6 feet apart. The path from the wheel nearest the wet end passes through the roll tank by means of a water gate either end.

The two wheels at the dry box end ("dry end") run in a vertical plane side by side.

Towards the under side of the upper two paths, which travel from the wet to the dry end, and the upper side of the under two paths of the pin belt (*i.e.*, the side not taken up by the film and teeth) hot water trunking is placed. This trunking is rectangular in section (approx. 6 in. \times 1½ in.). The side of the pin belt bearing the film is protected with wooden covers which are hinged for easy access.

The temperature of this heated surface (known as the "table")

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is controlled. The greater the temperature the greater the contrast. There is an increased colour density in the shadows, giving in severe cases "off ratio" defects. It is therefore Technicolor policy to keep these table temperatures constant according to a standard technique by means of mixing valves.

The matrix and blank in close contact, and held in register by the pin belt, emerge from the water gate (nearest the dye end) of the roll tank, and pass under the large seating belt. This seating belt is a loop of copper strip, about 9 inches diameter, similar to a piece of negative perforated cine film, but having smaller perforation on the track side. These perforations are seated over the teeth of the pin belt by the pressure or weight of a large rubber treaded roller, there being also a small roller 3 inches away to assist the "take off" of the loop from the pin belt. The large seating belt is followed by the small seating belt. The latter is similar to the first but only forms a loop 7 inches in diameter. It has only one seating roller and is of less weight.

The object of the seating belts is to ensure the correct seating of the blank and matrix perforations around the pin belt teeth. Incorrect seating of the blank and matrix would cause transfer around the perforations. Results of this are to be seen in the form of half round areas of colour with sharply defined edges against the perforations. The defect is most noticeable on the non-track side.

A close contact between blank and matrix is still further ensured by the use of two weighted rollers, the first having a 4 lb. weight attached, and the second having one of 9 lb.

After these pressure rollers a sucker is placed to remove surplus water from around the perforations and pins. This is then followed by a blow-off to remove any surplus water drops from the cell side of the blank.

It is on this part of the pin belt between the blow-off and the tables that the "sync. marks" printed on the matrix and blank are checked to ensure against "out of frame" and "out of sync." (out of rack) defects. If such a defect does occur, the number of perforations, frames, or feet, out of sync. are measured and the necessary length of leader attached to the next roll of blank or matrix (whichever is applicable) to be run on the machine.

The pin belt is friction driven by the two dry end wheels, which are chain driven by a constant speed motor. This is the only motor on the colour bank that is not controlled, and is therefore the one that sets the overall speed of the machine, and is termed the main drive motor.

After completing the two circuits on the pin belt, the blank and matrix leave it at a point in line with and about $3\frac{1}{2}$ ft. below the seating belts.

The parting is effected by both blank and matrix running over a roller called the "stripping roller" whilst the pin belt continues along its horizontal path.

The blank runs vertically downwards in a flat plane whilst the matrix runs off at an angle of 45° downwards with a twist through 180° . It is this twist that brings about the stripping or parting of the two films. A mercuroid switch is placed on the blank just after the stripping point.

Both matrix and blank run over pulleys (both now being emulsion downwards) and run in horizontal paths towards the dry end, immediately below the lower tables. The blank runs horizontally in a dry box from end to end three times before emerging at the dry end to travel to the top of the machine and over a captive diabolula (which by means of a cord governs the speed of the matrix dry box drive motor). The drive for the blank dry box is supplied by a friction loaded rubber covered pulley powered by a chain from the main drive motor.

The blank, after passing a mercuroid switch, travels into the pre-wet bath of the succeeding colour bank (*i.e.*, the cyan).

The matrix after leaving the stripping wheel runs under the blank dry box to a point below the large dry end pin belt driving wheels, where it travels through the floor to the "deco" tank containing sodium carbonate (not circulated). The object of this tank is to wash the matrix clear of any remaining dye (a mercuroid switch being placed at the entry into this tank).

After this the matrix passes into a wash tank and then up through the floor into the matrix dry box at the end of the transfer machine. It leaves this to be rolled up on the take-up.

After re-winding and inspection by "matrix re-wind dept." it is held in readiness for a further transfer.

The cyan bank is identical to the yellow (the yellow and cyan banks being built side by side in one unit (this formed an original two-colour machine)).

The blank bearing the yellow and cyan dye image passes over to the magenta bank. This bank, and a disused one alongside, forms another of the original two-colour machines, and stands parallel to the yellow and cyan banks with a gangway about 6 ft. wide between them.

The magenta bank is very similar to the yellow and cyan, but has the following differences. A small tank containing alcohol, with a fixed elevator running in it, is placed between the wash back and roll tank. This is only used when a certain matrix is known to be bad for air and transfer. It is on the magenta that these defects are most pronounced. The softening effect of the alcohol on the dye laden matrix emulsion not only minimises the above defect but also increases dye spread.

The weights attached to the rollers after the seating belts are increased to 6 and 12 lb. respectively.

The table temperature on this bank is maintained 10° F. above that on the other two tables. The last two modifications are introduced in order to reduce the chances of air, and transfer.

The blank on leaving the magenta dry box passes over waxing rollers

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running over the perforation tracks. After this the blank runs past a mercuroid switch, on to the take-up elevator.

The mercuroid switch is a glass phial one-third filled with mercury, into which electrodes protrude at one end, the phial being mounted on an arm pivoted about two-thirds of its length. On the short arm two wheels are mounted so that they ride on either side of the film (*i.e.*, over the perforation tracks). The tension of the film running vertically causes the arm to remain horizontal. In the event of the film breaking, the weight of the glass phial, or mercuroid, on the longer arm, causes it to fall to a near vertical position, the mercury forming the circuit between the electrodes.

The closed circuit actuates a relay which stops the machine, rings a bell, and switches on a pilot light (each section having its own appropriate light). These lights are coloured either yellow, cyan or magenta, according to their colour bank.

The de-aerator is a machine situated on the ground floor (*i.e.*, the floor below the machine) and consists of a vacuum pump exhausting air from a cylinder containing pipes with fine jets protruding from them. Distilled water at 110° F. is pumped through these pipes and forced through the jets, to form a fine spray within the vacuum. The water is then sucked from the bottom of the cylinder and pumped up to the I.B. machine.

To be set against the great reproductive advantages of an imbibition machine, of which we are all aware, are the following disadvantages (not including the difficulties to be overcome in the production of matrices).

1. In the event of off-sync. or off-frame troubles, many feet of film might be run before the correction can be applied.
2. In the event of a machine stop at least two reels of production might be N.G.'d (the excessive waste in the "wash-back" causing no transfer from that part of the matrix).
3. Any machine stop of more than 3 minutes would cause permanent register trouble owing to distortion of the matrices on the hot tables (*i.e.*, at least two sets of matrices N.G.'d).
4. There must be a severe risk of a machine stop damaging a matrix or matrices as a result of "baking" on the tables—this would cause a failure to strip.
5. Any particle of dirt would give a defect many times its size—*i.e.*, the particle would probably be represented by a + colour density area (that is, if it adhered to the matrix before the dye tank). But if it was deposited on the matrix after the dye tank,

Fig. 3

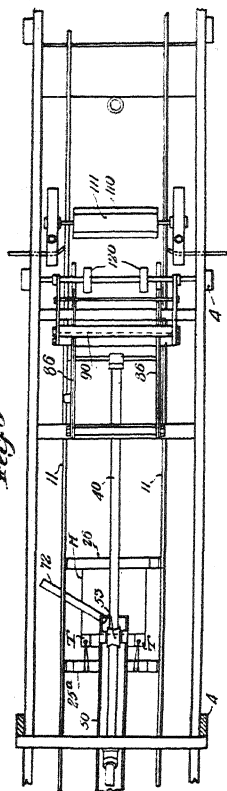


Fig. 5

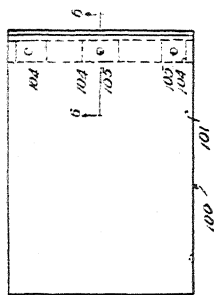
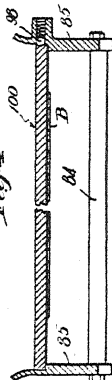


Fig. 4



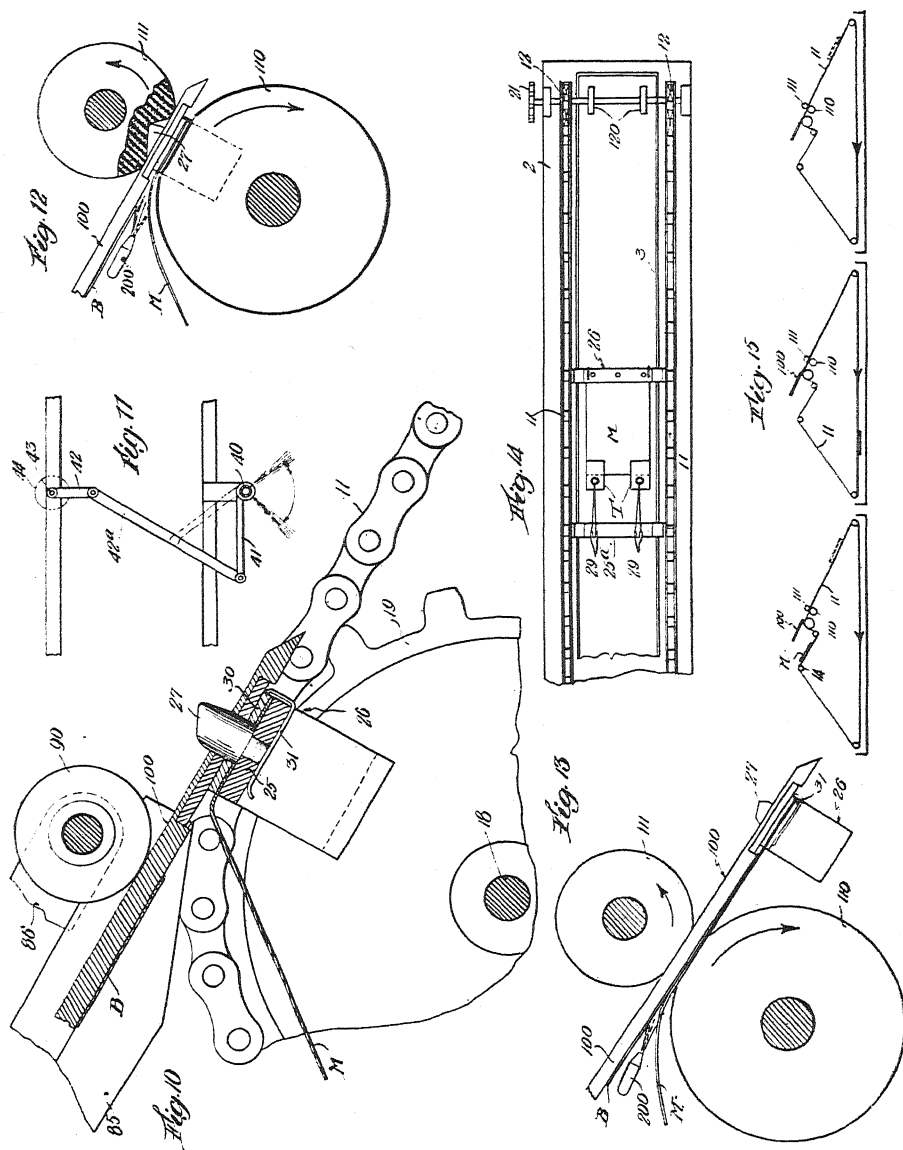


Fig. 249C.—Imbibition Printing Machine by I. B. Corporation. E.P. 487,941.

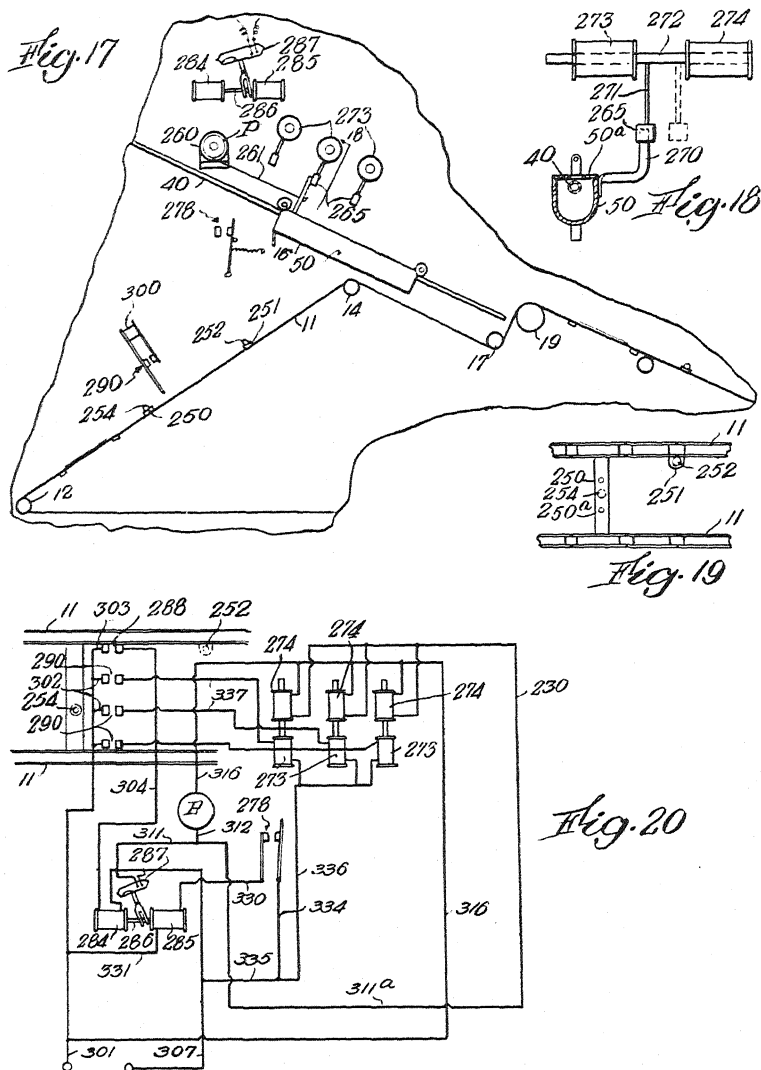


FIG. 249D.—Imbibition Printing Machine by I. B. Corporation. E.P. 487,941.

- or at any time on the blank, it would be represented by a surrounding area of transfer (if on the matrix by one colour; if on the blank by all the succeeding colours).
6. Any form of emulsion damage either on the matrix or blank would be represented by either + or - colour density—usually both.
 7. If the blank emulsion is too hard — transfer would ensue, and possibly — air. If the blank emulsion be softened to overcome these two defects, bleeding or dye spread would increase. A mean technique has to be pursued which admits both defects to a lesser degree.
 8. There must exist the continual problem of register, owing to the stretch and shrinkage of new and old matrices (besides the troubles experienced with negatives, masters, dupes, etc., in printing).
 9. A matrix may be unreliable in its "keeping qualities," it may distort, perish or shrink at an early age, and cause breakage, damaged perforations, and jumping on the pin belt—this would cause off-sync. and off-frame troubles.
 10. The possibility of "transfer for air" (see former explanation) must always be present.
 11. Quite considerable trouble could be caused by transfer "edge" owing to poor seating around the pins. This might be caused by a mild form of shrinkage (either blank or matrix).

The above defects are peculiar to a pin-belt machine. But the more usual defects are still present, *i.e.*, scratches (this applies to matrix as well as blank) either negative or positive, on cell or emulsion, operational errors, dye and colour fluctuations, etc.

The following description of an imbibition printing machine patented by the I.B. Corporation is concerned with the means at present employed by Technicolor in U.S.A. and Britain.

B.P. 487,941. Dye-Impression Printing; Electric Control Systems. I.B. Corporation. Dec. 28, 1936, No. 35509. Convention date, Dec. 28, 1935.

(Reference should be made to Figures 249A-D.

In the process of an apparatus for printing in multicolour from a set of photographically prepared gelatin matrices, the blanks to be printed and the matrices are fixed to supports and carried through cycles, the cycle for the matrices being automatically controlled and including the steps of applying excess dye to the matrices, removing a part of this dye, and pressing the matrices into contact with successive blanks. Preferably the matrices are overexposed and overdyed so that the removal of dye results in a gradation which corresponds to the straight part of the

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characteristic curve of an emulsion. The removal of dye is also adjustable to attain colour balance in the resulting pictures and may be effected by sprays. Apparatus for the process comprises a set of machines corresponding to the number of colours to be printed. In the form shown, each machine comprises a dye bath 3, Fig. 1, endless bands 11 having supports 26 for the matrices, an oscillating spray pipe 171 for applying further dye, washing sprays 72 for removing surplus dye, and rollers 110, 111 for pressing the matrices into contact with the blanks. The dye removal sprays are delivered by an oscillating tube 40 and may be deflected by a movable hood 50 to vary the quantity of dye removed. The matrices are carried by blocks 26, Fig. 10, having pins 27 which enter holes in the forward end of plates 100 carrying the blanks B. Automatic control of the hood 50 may be provided. As shown in Fig. 17, a pin 252 mounted on the endless carrier 11 in advance of the matrix, closes a switch to set in operation a motor P which draws the hood 50 upwards. At the top of its travel, a pin on the hood closes the cut-out switch 278 causing the motor to stop and the hood returns under gravity. A second pin 254 occupying a pre-set position on the front of the matrix support 26 then closes one of the switches 290 bringing a stop 265 into the path of the hood 50 as it returns. Preferably the dye bath and sprays are maintained at a raised temperature. Suitable dyes for a three-colour process are Erioglaurine for the cyan component, acid fuchsin for the magenta, and resorcline yellow for the yellow.

Technicolor General Procedure

Activities before photography:

Colour Control:

- (a) Colour design of the sets.
- (b) Costume colour selection.

Set colours are chosen:

- (a) For hue, chroma, and value in relation to the costumes.
- (b) For relative importance of the set.
- (c) For cutting and relationship to other sets.
- (d) For relationship of above factors to the script.

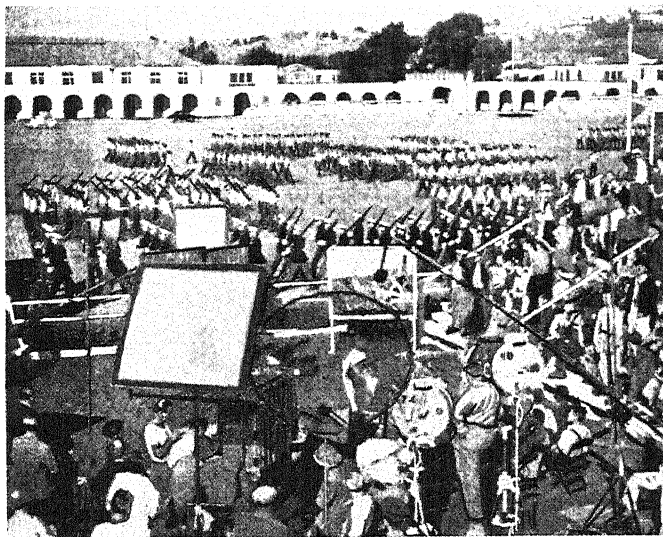
These factors, when decided upon, form the "colour score."

A colour control department advises on these factors.

Make-up.—Handled by the studio, but the colour cameraman often intervenes. For example, there may be compensation for sunburn during or following exterior work. Neck, throat, hands and arms require treatment. Babies frequently require no make-up. Object of make-up is largely to reduce range of flesh colour observable in various individuals. Critical care must be given to close-ups.



(By courtesy of Paramount Pictures)



(By courtesy of 20th Century Fox)

FIG. 250.—Colour booster light shot.

Colour follow shot (*above*).

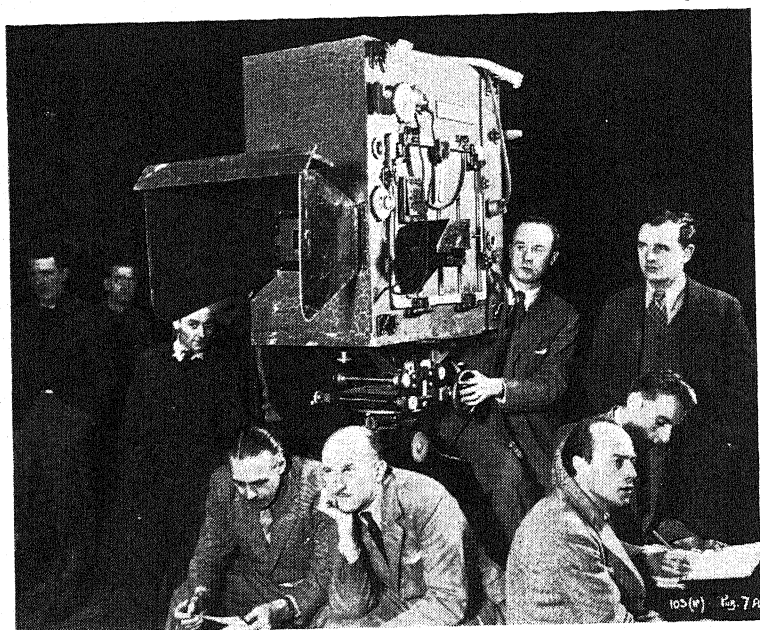


FIG. 251.—Technicolor camera in Blimp. In action for the Archers' production, "A Matter of Life and Death."

(By kind permission of Michael Powell and Emeric Pressburger)

Photography.—Technicolor cameras are filter-balanced to average daylight. Colour-temperatures should not vary by more than 250° .

For studio work the following sources are used, but in each case they are filtered to match a standard daylight. Thus the filters or stock in the camera are unaltered:

High-intensity arc.
White-flame arc.
Tungsten filament bulbs.

The General Electric C.P. tungsten incandescent bulbs are burnt at a colour-temperature of $3,380^{\circ}$ K., and a MacBeth artificial daylight glass filter is used to transform the radiation to a colour-temperature of $6,000^{\circ}$ K. Unfiltered inky lights are used to simulate firelight glow. Coloured lights may be used for special effects. Large sets are usually illuminated by arc lighting with occasional auxiliary inky units. Small sets are sometimes entirely lit by inky units.

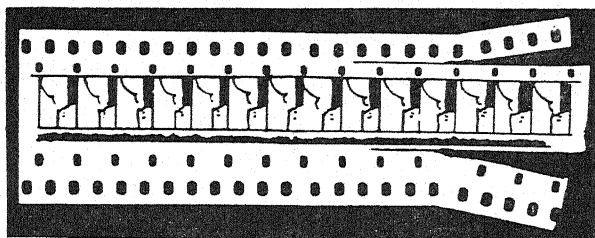


FIG. 251A.

For exteriors, metallic reflectors are undesirable owing to sunlight directly reflected varying in colour-temperature from average daylight.

For process projection special plates are printed of the required contrast density and colour, depending on the particular background projector to be employed. Multiple projector heads project up to three matched prints. Background screens have been photographed up to 28 ft. in width. Care has to be taken to achieve foreground-background balance.

Lenses on the Technicolor camera are available of the following foci: 25, 35, 40, 50, 70, 100, 140 mm. These all fit into calibrated mounts that fit on to a master focusing mount. Generally, focusing is checked by measurement. Eye focusing has been found faulty. Stops are calibrated on an arbitrary arithmetical scale. A very original Technicolor speciality is the follow-focus aid which takes the form of a pair of Selsyn motors.¹ One is attached to the lens mount, and the controlling motor is held in the technician's hand, or fastened to some support if desirable, permitting the technician to be 50 ft. or more

¹ Now available on the Dufaychrome camera.

away from the camera, and yet to maintain control over the lens focus, even though the camera is "blimped."

The motor arrangement is highly flexible. There are eight types of motor and eight combinations of motor-to-camera gears, all of which can be changed in the field. The cameras can also be operated in reverse. Speeds in excess of 24 pictures per second are not permissible.

The camera can be mounted on anything from a spider to a high tripod, and on any other piece of equipment as may be desired, such as dollies, three-wheel perambulators, four-wheel velocitators, booms, rotating mounts, etc. Special mounts have been used for air photography and for underwater work. Speed cameras have been made to shoot up to 96 pictures per second. The threading time of a Technicolor camera is about 3 minutes.

Technicolor cartoons are photographed by normal cameras using the successive exposure method with either rotating or sliding filters. The negative is printed on a skipping intermittent printer. All optical and trick effects known to black-and-white can be used for Technicolor.

Negatives are developed at night and black-and-white rush prints delivered the following afternoon. Colour rush prints are delivered the following evening.

Winton Hoch of the Technicolor Motion Picture Corporation wrote in 1942: "The negative reports and all laboratory contacts are handled for the cameraman through the Technicolor camera department, which also checks the daily log-sheets, and by these log-sheets keeps a very complete record of every production and of every scene photographed on that production. The records have proved invaluable, not only to the cameraman, but on many occasions to the director and others participating in the production."

Technicolor "Monopack"

With regard to the use of Kodachrome monopack for the Technicolor record, Hoch says: "The present monopack process in latitude, visibility, and tone rendition is satisfactory, but the picture texture in grain and uniformity has not attained the smooth, fine texture of three-strip." Progress since this was written (1942) has not been marked by any radical improvement.

Of 16-mm. Kodachrome monopack for Technicolor, William Stull (*American Cinematographer*, September 1941) says that the Technicolor copy "had less of the appearance of a dupe than he had considered possible" and that the "tonal range and gradation were comparable with the original Kodachrome or standard Technicolor." We cannot agree with this verdict.

The monopack is used in cameras which are fitted with 25-mm. lenses, and has, in consequence, a characteristic perspective and depth

of field which are reproduced on the 35-mm. enlargements to give what Stull describes as "an uncanny effect on the screen."

Technicolor recommend that the Kodachrome exposure for Technicolor reproduction should be on the low side of normal.

Darrel Catling, British director, has recounted his experiences during the making of a documentary which was shot entirely in monopack. His statements do not support the absurdly exaggerated reports which have been quoted from American journals. It is quite clear that after all the fuss there has been some disappointment. The character of the result is only what was predicted by the writer seven years ago, when Dr. Kalmus confidently predicted the demise of the beam-splitter camera. How anybody familiar with the theory of colour photography could have imagined for a moment that it was possible to get prints from negatives extracted from a 16-mm. Kodachrome film which could compare with direct separations defies imagination. Even "electronic" masking would not crack this nut. The film was "English Village," the first British monopack effort. Catling says that they included a colour chart for every shot. An ultra-violet absorbing filter was used (Y-1). The film in this instance seems to have been 35-mm. Kodachrome, since a Vinten camera was employed. Small hand tests were processed at Harrow, but the main film had to be sent to Rochester for processing. Finishing on September 12, no rushes were available until December 3, when a black-and-white cutting print arrived. The colour pilots did not arrive until December 31. "They were surprisingly good, though some scenes seemed to be on the thin side, while in others there was an occasional fluctuation of colour. Greens were rendered on the hard side, and light-soaked whites had a pinky halation. Flesh tints tended to be hot." The last material did not arrive until April 28. The following August (1944) Mr. Catling had not seen his film. It therefore does not seem to be a very practicable proposition in England as yet.

Principal U.S.A. productions on monopack so far have been:

- | | | |
|--------|---|---|
| 16 mm. | { | "Thunderhead—Son of Flicka." |
| | | "Memphis Belle." |
| | | "Fighting Lady." |
| | | "Marines at Tarawa." |
| | | "Report from the Aleutians." |
| | | "Saludos Amigos." |
| | | Some Fitzpatrick Travelogues. |
| | | "XIV Olympiad—The Glory of Sport" (Part). |

References

- EDOUART, A. F., "Paramount Triple-Head Transparency Process Projector," *Journ. Soc. Mot. Pic. Eng.*, 33 (Aug. 1939), p. 170.

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- "The Paramount Transparency Process Projection Equipment," *Journ. Soc. Mot. Pic. Eng.*, 40 (June 1943), p. 366.
- HOCH, W., "Technicolor Cinematography," *Journ. Soc. Mot. Pic. Eng.*, 39 (Aug. 1942), p. 96.
- CATLING, D., "Shooting in Monopack," *Brit. Journ. Phot.* (Aug. 11, 1944), p. 282.

Résumé of the Principal Technicolor Printing Patents

Excerpts from the Specifications or abridgements by permission of the Controller of H.M. Stationery Office.

E.P. 132,580. Comstock, D. F., and Technicolor, 1918.

Coloured light is used in printing which will reverse or neutralize the effect of difference in the range of film densities in the negative (gamma control). For negatives having a high contrast gradient, printing light is used of such wavelength as will produce a positive having a comparatively low contrast gradient, and vice versa. Thus, for a two-colour process employing red and green taking filters, ultra-violet and blue filters may be used for printing the positives. The process is especially applicable to multicolour printing on a single film in which the contrast gradients cannot be equalized by development. Wall says [4]: "This principle was first suggested by Lemann [5] and had been in constant use for many years."

E.P. 188,329. Comstock, D. F., and Technicolor, 1921.

Describes the exposure of two films through the celluloid and the superposition of the two films by cementing them back to back before development. Technicolor used double-width film at this period, and after printing it was folded with the images outwards. It is stated that the developer is to be pyro, subsequently bleaching with potassium ferrocyanide, fixing with hypo, etching away the soft gelatine, and staining the relief images so obtained.

E.P. 204,404. Comstock, D. F., and Technicolor, 1923.

The imbibition film is mounted for development after exposure on a thin metal band, or backing. Steel plated with copper is suggested. The film is cemented with a layer of binding material such as amyl acetate and lacquer, and fed through pressure rollers and heated to 120° F. for 30 minutes. The metal strip ensures perfect registration when printing by imbibition upon a blank film.

E.P. 241,052. Andrews, J. M., and Technicolor.

Processing machinery for dissolving away the unhardened gelatine with hot water which is flowed on to the film at opposite edges from several nozzles. The hot water has a temperature of 120° F.

E.P. 263,331. U.S.P. 1,677,665. Weaver, E. A., and Technicolor, 1926.

The gradations in the high-lights of imbibition relief images are made more gradual than those in the half-tone parts by exposure of the film

to uniformly distributed light, either previously or simultaneously with the contact printing of the image proper. The film may be rendered absorptive to light of a particular colour, and the uniformly exposing light may be of that colour. The exposure to uniform light may be approximately the threshold exposure, and both exposures are made from the same side of the film, either from the emulsion side or the celluloid side. Either one or all of the images of a multi-colour positive may have been thus exposed to uniformly distributed light.

E.P. 263,650. Weaver, E. A., and Technicolor, 1926.

The densities in the shadows of imbibition reliefs are made at least as great as in the half-tone portions. The film is dyed with a dye absorptive to light of short wavelength, and printing is done with a light of short wavelength mixed with a light of long wavelength. A sharp-cutting dye such as naphthol yellow is used, and it is used in as concentrated a form as possible. Quinoline yellow is mentioned as a restrainer permitting the use of maximum concentration of naphthol yellow.

E.P. 264,369. Ball, J. A., and Technicolor, 1926.

Printing apparatus for imbibition matrices. The machine enables one negative bearing two-colour records in alternating sequence to print two separate positive films; two printing lights are employed, one for each gate. The type of negative used in this printer is that obtained with a beam-splitter camera of the type described in E.P. 194,971 (see Chapter V). The arrangement of the images is the same as in E.P. 349,318.

E.P. 270,279. Technicolor Motion Picture Corporation, 1926.

Dyes for imbibition printing are highly purified in such a way as to remove any solid matter or impurities, so that the dye will be absorbed upon the printing matrix in accordance with the density of the printing image, without the formation of self-agglomerating components, and will also be freely imbibed into the receptive gelatine surface without diffusion and without the formation of layers or matter which tends to adhere to the surface or becomes detached from the printing matrix. The dye solutions may be "egg-treated"—namely, by the addition of the white of egg or like amphoteric colloid followed by coagulation, as by boiling, and removal of the coagulated colloid together with extraneous solids or solid-forming constituents. To the dye solution may also be added a viscosity agent to prevent lateral diffusion, and this may comprise a second dye having relatively low penetration or dispersion, and high definition with respect to the film to be printed. Two acidified dye compositions for red and green respectively are specified.

E.P. 270,280. Atwood, F. C., and Technicolor, 1926.

Imbibition reliefs are prepared by treating the gelatine with a bichromate hardening agent and an organic acid, drying promptly to a firm consistency and subjecting it to an elevated temperature. A coating may consist of, for example, a gelatine solution containing potassium bichromate to the extent of 5 per cent. of the gelatine used, and, say, about three drops of acetic acid per 100 c.c. After drying the film it is uniformly heated over a prolonged period, say to 90°-100° F. The surface of the film is then washed to remove any excess of hardening agent and thoroughly dried. The heating may be done in a heated chamber or by heated rollers. It is noted that the reduction of the chromium before drying the film should be avoided.

E.P. 288,146. Kienninger, J. F., 1927.

A method for hardening the gelatine of the imbibition blank film. An alkali bichromate is mixed with the gelatine together with an activating agent (*i.e.*, an alkali sulphite) and a restraining agent (*i.e.*, ammonium hydroxide), and the latter is removed to permit the hardening action to proceed. The restraining agent may be removed at the time of setting and dehydration of the colloid. The hardening action is controlled by the acidity or alkalinity of the mixture and by the extent of dehydration and temperature.

E.P. 300,818. Ball, J. A., Technicolor and others.

Imbibition printing apparatus. The films are fed along converging paths and a retarding force is applied to both films in advance of their point of contact, so that if either of the films has shrunk it receives the whole of the retarding force until it is stretched to conform to the other film, and then both films are subjected to the force.

E.P. 307,659. Comstock, D. F., and Technicolor, 1928.

This patent is so outstandingly important in the history of the Technicolor process, and the specification so completely describes the nature of the imbibition process, that we do not hesitate to reprint practically the whole specification for the instruction of students (Figs. 252A-D):

The printing or stamping of images on blank films presents very exacting problems even in a single colour, but in printing or stamping pictures having a plurality of colours the problem is especially difficult to accomplish satisfactorily in actual practice.

For example, in producing cinematographic films in colour by the imbibition of dye upon a film from one or more matrix films, where the images are to be printed in different or complementary colours in superposition—*e.g.*, where one image represents the red (or red-orange) aspect and another represents the green (or blue-green) aspect of the scene—either on the same or on opposite sides of the film, the complementary images must be transferred and registered with an extreme degree of accuracy.

Among the problems encountered in the various operations involved are those of securing exact registration of the images and of minimizing or preventing the lateral spreading of the dye in any one colour picture during the printing of another colour picture. Moreover, when an attempt is made to print a series of pictures upon a continuous strip, as in cinematographic films, serious difficulties are encountered due to the character of the material employed. The film stock usually employed shrinks with age and as a result of the alternate wetting and drying incident to its development and use, and varies in dimensions with temperature and humidity, while the gelatine coating on the surface which absorbs the dye swells appreciably when wet. The difficulties from this source are further increased by the fact that the pictures are arranged in sequence upon a long strip of such material from which they are printed upon another strip of like characteristics. Moreover, the images upon the finished film are greatly magnified to many times their printed size when projected upon a screen, and this causes any

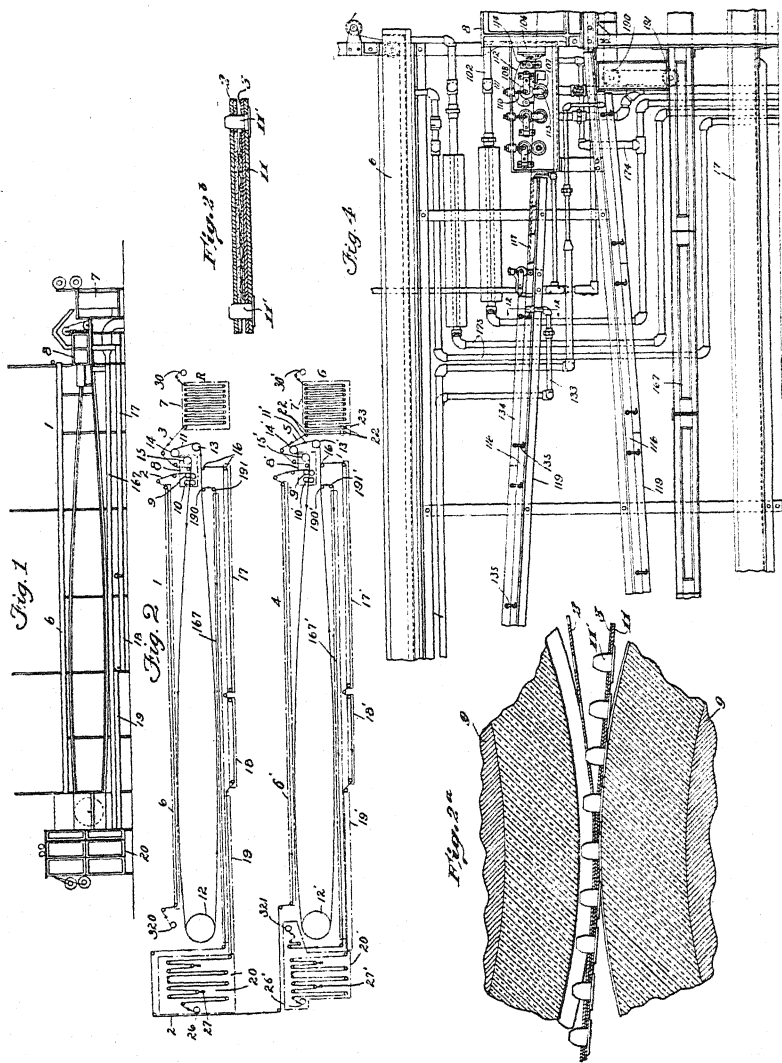


FIG. 252A.—Machinery for imbibition printing by the Technicolor Process. E.P. 307,659.

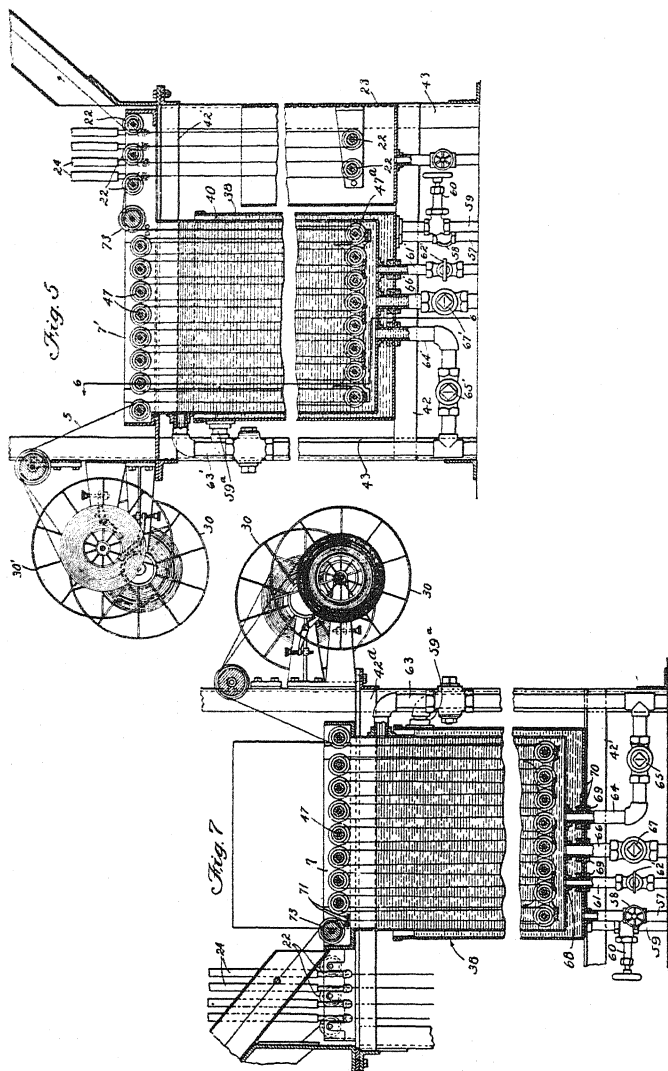


FIG. 252B.—Machinery for imbibition printing by the Technicolor Process. E.P. 307,659.

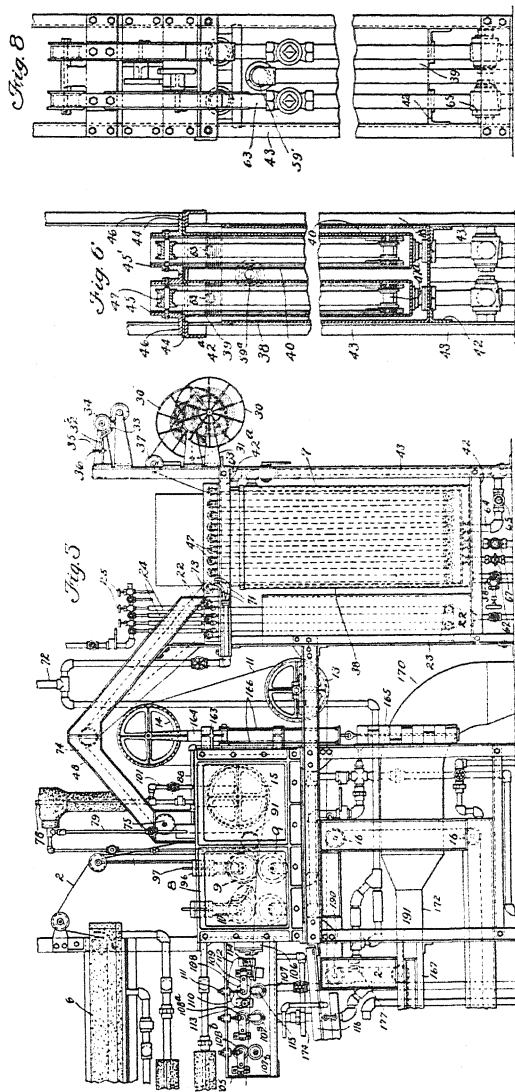
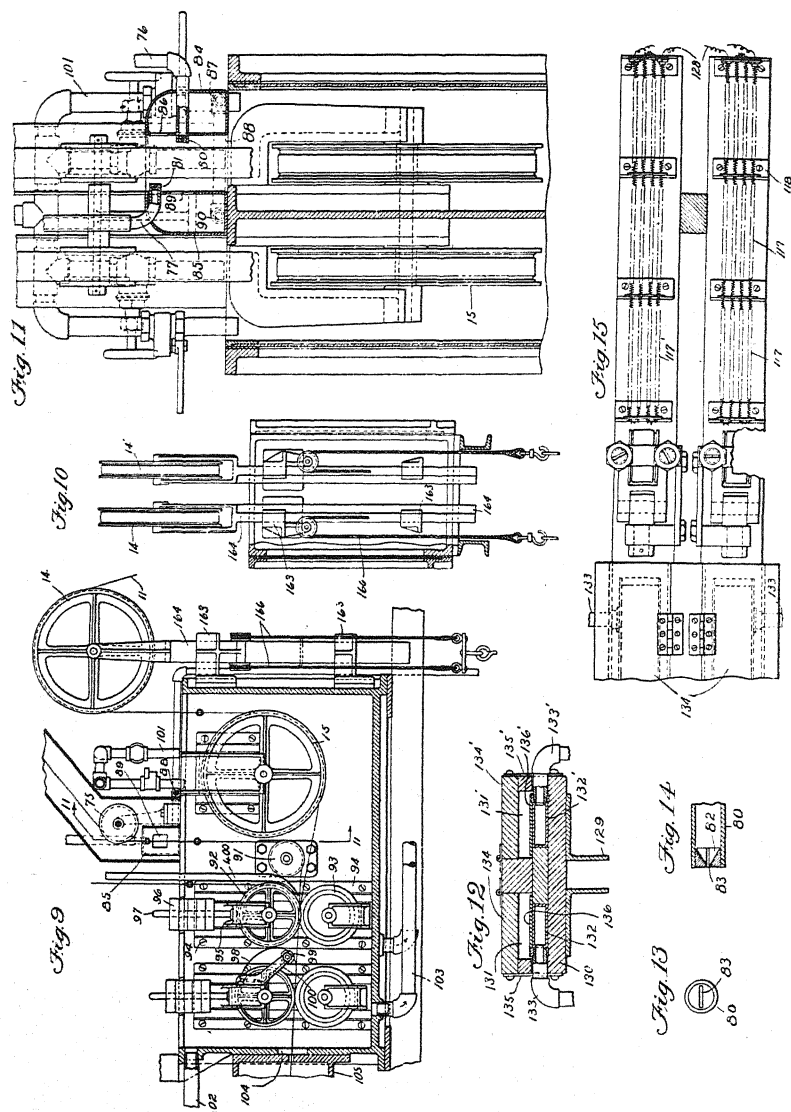


Fig. 252C.—Machinery for imbibition printing by the Technicolor Process. E.P. 307,659.



defects due to imperfect registration to be correspondingly exaggerated. Therefore it is absolutely essential in order to have a satisfactory transposition that the strips be brought into substantially perfect registration at the time of contact and then so maintained for a substantial period of time or through a relatively long path during which the transposition of the dye (from the wet portions of the matrix corresponding to the images to be transferred therefrom) to the blank is effected.

The present invention presupposes the use of either a single matrix film or for colour printing a plurality of matrix films corresponding to the several colours to be employed, and a blank film upon which the reproduction is transferred from the matrix film by imbibition. The method of the invention includes broadly the steps of impregnating the matrix or printing film with a suitable dye solution, removing unabsorbed liquid from the surface thereof, bringing the dye-wet surface of the matrix film into predetermined, uniform, and intimate contact with a previously wet film blank to be printed (preferably effecting such contact at a point where both films are thoroughly immersed in a liquid), simultaneously or successively registering the blank and the film with each other and with a backing strip of relatively permanent and predetermined dimensions (such as a continuous metallic belt) causing the belt and films in registered association therewith to pass through an extended path (*i.e.*, one requiring a sufficient time of traverse to permit complete imbibition of the dye from the matrix film to the film blank), followed by successive or simultaneous separation of the films and backing strip and drying in readiness for use, or, in the case of making multicoloured reproductions, passing the thus printed film blank through a second series of steps substantially identical with and controlled or synchronized to proceed in step with the first.

The matrix film is continuously withdrawn after separation from the film blank and metal backing, and passed through a "decreaseinating" solution, that is to say a solution for removing the dye and dye solution completely therefrom and leaving the film in suitable condition for subsequent re-use. It is then passed through washing and drying chambers, preferably under regulated tension and at a regulated speed conveniently imparted to it by winding upon a positively driven winding drum, which may in turn be controlled and regulated by the effective tension of the film. As thus gathered on the reel the film may be returned to the entrance end of the machine for re-use as before.

The apparatus of the invention includes the sequential arrangement of means for effecting the printing of films by imbibition, generally comprising means for wetting or dyeing a matrix film, means for wetting the blank film to be printed, means for effecting intimate contact between the appropriate surfaces of the films (preferably while submerged in a liquid), means for registering said films with respect to each other, backing means for conveying the thus registered films in undisturbed contacting relationship through a prescribed path (such as a continuous metal belt), means for pressing said films together and against the backing, means for conveying the same in such contacted relationship through an extended path, by means of the backing under controlled and predetermined conditions, means for subsequently separating and drying the printed film, means for separating, decreaseinating, rinsing, and drying the matrix film, and means for guiding the metallic belt to the origin of its circuit. Means are likewise provided for conveying the matrix and blank films (after separation from the backing) through the apparatus at a suitably regulated rate of speed, so controlled as to provide uniform movement and tension upon the film without disrupting or wearing the same or permitting it to become slack. Means also are included whereby two or more successive printings upon the same film blank may be effected in a continuous sequence of operations.

A typical adaptation of the invention will be described with reference to the printing of two-coloured reproductions upon transparent cinematographic films, a specific embodiment of the apparatus therefor being shown in the accompanying diagrams, in which (Fig. 252, A-E):

- Fig. 1 is a general side elevational view showing one of two units arranged in parallel;
- Fig. 2 is a diagrammatic view similar to Fig. 1 but showing both units (for printing with red and green dyes respectively) as though arranged in superposed parallelism, the unit for red dyeing (R) or forward unit as viewed in Fig. 1 being raised above that for green dyeing (G);
- Fig. 2a is a fragmentary detail view showing the pin belt, films and pressure rolls in longitudinal section;
- Fig. 2b is a transverse section of the films and belt;
- Fig. 3 is a fragmentary detail view of the right-hand section of the red-dyeing apparatus as viewed in Fig. 1;
- Fig. 4 is a fragmentary elevation, including and continuing from the left-hand side of Fig. 3;
- Fig. 5 is a longitudinal vertical section of the rear or green dye tank as viewed from the rear with respect to Fig. 1;
- Fig. 6 is a cross-section of both the red and green dye tanks in the plane of line 6—6 of Fig. 5;
- Fig. 7 is a longitudinal vertical section of the front or red dye tank as viewed in Fig. 1;
- Fig. 8 is an end elevation of both tanks from the right-hand side of Fig. 7 (or Fig. 1);
- Fig. 9 is an enlarged longitudinal vertical section of the water tank or contact chamber as shown in Fig. 3;
- Fig. 10 is an end elevation viewed from the right-hand side of Fig. 9;
- Fig. 11 is a cross-section and view on line 11—11 of Fig. 9 in the direction of the arrows;
- Fig. 12 is a view on line 12—12 of Fig. 4;
- Fig. 13 is an end view of a nozzle;
- Fig. 14 is a vertical section through Fig. 13;
- Fig. 15 is a plan view of the heating coils;
- Fig. 16 is a side elevation of Fig. 15;
- Fig. 17 is a view on line 17—17 of Fig. 16;
- Fig. 18 is an enlarged detailed section along line 18—18 of Fig. 17;
- Fig. 19 is an end elevation of one unit from the right-hand side of Fig. 15;
- Fig. 20 is a detailed vertical section on line 20—20 of Fig. 19;
- Fig. 21 is an enlarged fragmentary view of elements indicated in Figs. 1 to 4, including the decreaseinating and rinse tanks, the drying conduit and water-removing device;
- Fig. 21a is a fragmentary plan view of the drying conduit;
- Fig. 22 is a plan view of the suction or water-removing device;
- Fig. 23 is a side view of Fig. 22;
- Fig. 24 is a section on line 24—24 of Fig. 22; and
- Fig. 25 is a longitudinal section through one of the pulleys in the dye tank over which the matrix moves.

Referring to the drawings (Figs. 1 and 2), the apparatus illustrated includes two units (R and G)

arranged in substantially parallel relationship for the continuous, successive printing of a blank film strip first with a red dye (R) and then with a green dye (G), thereby producing a complete colour reproduction on the surface of the completed film. Fig. 1 shows a side elevation of the apparatus, the red-dye unit (R) being in front, while in Fig. 2, which is diagrammatic only, the red-dye unit (R) is raised to disclose the green-dye unit (G) therebehind and the parallel relationship of parts and orderly sequence of operations in the two units.

The red-dye unit (R) comprises generally a relatively extended structure 1, and means associated therewith for bringing the film to be printed 2 into intimate contact with the red-printing matrix film 3 and conveying the films in contact through an extensive path, means for separating the printed films and passing the film to be printed 2 to the green-dyeing unit (G) comprising a structure 4, which is arranged parallel to and is substantially identical with the structure 1, and means for effecting like contact with a green-printing matrix dye 5.

The unit (R) includes means for wetting the blank film to be printed, such as a long water tank 6, and means, such as dye tank 7, for wetting and dyeing the matrix film. Means are also provided for effecting an accurate and predetermined contact between the dye wet matrix and water wet film blank, including a water tank 8, provided with guide pulleys 9 and 10, adapted to receive the continuous metal belt 11, and also the films 2 and 3, therebetween. The belt 11 is preferably a thin and flexible but resilient strip or belt, conveniently made of non-corrosive and non-corrodible metal such as tin-plated steel. The pulleys 9 and 10 have rubber-covered peripheries grooved to receive the heads and ends respectively of the pins 11¹ (Figs. 2a and 2b). For example, the strip may be approximately 0.005 in. thick with a 0.001 in. coating of tin on each side. Straight-sided projecting pins 11¹ are arranged at accurately spaced intervals and in accurately parallel rows along the longitudinal margins of the strip but slightly spaced from the edge (Figs. 2a and 2b). The pins are preferably rounded at the top but have straight, substantially parallel sides, especially adjacent to their lower ends. The pins may be welded or soldered to the back of the belt (Figs. 2a and 2b). The belt 11 is carried through a closed circuit over a pulley 12, of larger diameter at the opposite end of the unit and internally contacting pulleys 13 and 14, and under pulley 15 (positioned in tank 8), which engages the exterior side of a belt. The pins may fit the sprocket holes in both dimensions or the pins of one row may fit longitudinally of the film and the pins of the other row transversely of the film.

Means are provided for separating the printed film from the film matrix 3 and belt 11, including pulleys 190 and 191, and for removing the film matrix 3 from the belt 11, such as pulleys 16. Means are also provided for treating the separated films for decroceinating, rinsing, drying, and reeling the same, ready for re-use. These means in the illustrated embodiment comprise in series below the machine and extending substantially throughout its length a decroceinating tank 17, a rinsing tank 18, a horizontal drying chamber 19, and a vertical drying chamber 20.

The second unit G (in which certain of the like parts are indicated by like numerals primed) has a wetting tank 6¹ for the printed blank film 2 from the unit R, and a dye-tank 7¹ (Figs. 2 and 5) for the green-dyeing matrix film 5, followed by rollers 22 conducting the film through a supplementary tank 23, having water showers 24 positioned thereabove with valves 25 (Fig. 3). These tanks are followed (Fig. 2) by a contacting chamber such as water tank 8¹, with pulleys 9¹, 10¹, 12¹, 13¹, 14¹, 15¹ respectively for the endless belt 11¹—substantially identical with those described with reference to unit R—and also decroceinating and rinsing tanks 17¹, 18¹ and drying chambers 19¹, 20¹ respectively.

In the drying chambers 20, 20¹ automatic means for tensioning and taking up the matrix films are installed, such as the positively driven reels 26, 26¹ for taking up the dried matrix films 3 and 5, and tension weights 27, 27¹ are suspended by pulleys upon free loops of the film. Carrier reels 30 and 30¹ are mounted upon the common bracket 31 at the inlet end of the units R and G for feeding the matrix films to the apparatus. A supply reel for the blank film to be printed is mounted at 320 and a take-up reel at the end of the apparatus at 321. Above the matrix reels 30 and 30¹ similar reels (showing the hubs only, Fig. 3) may be mounted for carrying a film to succeed the matrix film in use—having brake mechanism (which is similarly provided on reels 30, 30¹ but not shown) comprising a lever 32 having one end 33 bearing upon the periphery 34 of the reel hub and the other end having a spring 35 carried upon an adjusting pin 36.

The unit R (Fig. 3) includes means for effecting the progressive and continuous wetting of the matrix film from reel 30 (with a red-dye solution) such as a pulley 37 and tank 7 having an outer shell 38 constituting a water jacket surrounding both the inner red-dye vat 39 of unit R and inner green-dye vat 40 of unit G (Figs. 3, 5, 6, 7 and 8).

The jacket 38 rests upon longitudinal angle irons 42, while the dye tanks 39 and 40 are suspended by flanges 44 at their upper edges upon angle irons 42a, which are parallel to and above the first pair. Both pairs of angle irons are in turn fixed to the vertical uprights 43. Above the flanges 44 are provided L-shaped supports 45, 45¹, each having horizontal members 46 resting upon flanges 44 and vertical members carrying bearings for a series of pulleys 47. A similar series of pulleys 47a opposite and offset with respect to the first are mounted in the lower part of each tank. Each pulley (Fig. 25) has a cylindrical surface 49 and end flanges 50 with intermediate guides 51 adapted to receive and support the edges of a film passing thereover. Each pulley is mounted at the ends upon bearings 52 having conical points 53 which are received in conical recesses 54 upon the ends of the pulley axis 55 and held in adjusted position by set-screws 56. Similar pulley construction may be used in other parts of the apparatus.

The outer jacket of the tank 7 is connected to a suitable supply of water through pipe 57 controlled by valve 58, outlet 59 controlled by valve 60, and an overflow outlet 59a. Red-dye tank 39 is likewise provided with an inlet 61 having valve 62, and an outlet pipe 64 controlled by valve 65 and overflow outlet 63. A supplementary drain 66 and valve 67 serves to withdraw the dye when it is to be discarded. Pipes 61, 64, and 66 pass through the wall and into tank 39 and are suitably joined by washers and nuts 68, 69, and 70. Green-dye tank 40 is provided with similar connections (Fig. 5) 61¹, 62¹, 63¹, 64¹, 65¹, 66¹, and 67¹ respectively.

At the exit end of tank 39 (Figs. 1, 3, and 7) nozzles 71 leading from compressed air line 72 are mounted on either side of the matrix film 3, which is carried upon pulleys 73, 74, and 75 located in conduit 48 and passes between a pair of inwardly directed water nozzles 76, 77 (Fig. 11). The latter are connected through pipe 79 to the main pipe line 78 which supplies the water tank 8. The nozzles 76 and 77 (Fig. 11) terminate in restricted openings 80, 81 having a conical wall 82 and horizontal aperture 83 (Figs. 13 and 14). The nozzle 76—80 passes through housing 84 which has an opening 86 opposite nozzle 81 to catch the water therefrom and an exit pipe 87. Nozzle 77—81 passes through housing 85 which has a similar opening 89 therein opposite nozzle 80 and an exit pipe 90. Exit pipes 87 and 90 lead through the common outlet 88.

Means for effecting registry and contact between the films 2 and 3 and metal band 11 consist of a pulley 91 in the tank 8, a pair of opposed compression rollers 92 and 93 (Fig. 9), the upper roller 92 being mounted in bearings 95 received in vertical guides 94 and provided with counter-weights 96 received upon the upright spindle 97, and a second pair of compression rollers 10 substantially identical with the first except that the upper roller is fitted with a belt 98 passing over an offset roller 99 mounted on the arm 100. The water tank 8 in which these elements are mounted is also provided with an inlet supply 101, an overflow outlet 102, and a drain pipe 103.

At the end of tank 8 is provided an exit aperture 104 (for the superposed films 2 and 3 and metal band 11) leading to the adjacent chamber 105 (Fig. 3) through an enclosing gate 106 which is followed in succession by a pair of rollers 107, 108 (the latter being mounted on lever 109 and pressed toward the other by compression spring 110 adjusted by screw 111), a belt 112 passing over roller 109 and also over supplementary rollers 113 and 114, and additional pairs of compression or guide rollers 107a—108a, 107b—108b. The chamber 105 is provided with drainage outlet 174. Extending from chamber 105 is provided a guideway 116 (Fig. 4) consisting of an angle iron framework and an enclosed conduit thereon leading to the pulley 12 (Fig. 2) and returning to the entrance end of the unit (Figs. 1-2). The first section of this guideway or conduit is left open and provided with electrical resistance heaters consisting of resistance elements 117 mounted in sheets of mica 123 (Figs. 17 and 18) by means of spaced uprights. The latter consist of L-shaped horizontal pieces 118 fixed to the guideway 116 (Figs. 16 and 17) by screws 119, and vertical members 120 having slots 121 for bolts 122 passing therethrough and adapted to support the vertical sheets of mica or other insulation 123, upon which the resistance elements 117 are supported by being passed through insulated apertures 125, and held in extended position by insulated terminal lugs 126, screw-threaded sleeves 127, and connections 128 leading to a suitable source of electric current. The heating unit and also the guideway or conduit 116 and associated parts are conveniently mounted upon an angle iron framework 129 and support 130 (Figs. 12 and 16).

Extending from the heating zone is provided an enclosed circuit corresponding to the path of the belt 11, formed by the guideway 116 made up of a series of enclosed chambers, comprising the upper chamber 131 (Fig. 12) having a cover 134, a lower chamber 132 separated from the upper chamber by plates or partitions 136, with pipes 133 leading into chamber 132 for circulating a cooling or heating medium such as water therethrough. The guideway 116 thus formed (Fig. 4) is followed by decroceinating tank 17 (for the matrix film 3) having entrance pulley 16 and exit pulley 137 (Fig. 21), a succeeding pulley 138, and a rinsing tank 18 with entrance and exit pulleys 139, 140, both of tanks 17 and 18 being provided with water inlet and outlet connections 141 and 142.

At the exit from tank 18 there is provided a blowing device 144 (Figs. 21-24) mounted on bracket 145 having guide rollers 146 on spindles 147 fixed by screws 148 to the casing which contains a chamber 149 closed by a plate 151 having a central opening 152 for connecting to a source of compressed air (not shown). Intermediate of the pulleys 146 and on opposite sides of the film 3 are provided a pair of tabular chambers 154 fixed to the plate 151 by screws 153, 155, each of said chambers opening (at 156) into chamber 149 and being connected by a pair of parallel transverse tubes 159 spaced apart to permit the passage of matrix film 3 therebetween, each of the tubes 159 opening into the chambers 154 at both ends 160. The transverse tubes 159 have longitudinal slits 162 in opposed relationship and directed at an angle to the opposed faces of the film 3. The blower 144 is followed in succession by drying chambers 19 and 20 (Fig. 1) which have already been described.

The pulleys 14 and 14¹ (Figs. 9 and 10) for carrying the endless belt 11 are mounted upon uprights 164, which in turn are slidably mounted in vertical guideways 163 and tend to be moved upwardly by the force of weights 165 (Fig. 3) attached to the ends of the cord 166 which is passed over a fixed pulley.

For receiving the printed film blank 2 a longitudinal conduit 167 (Figs. 21 and 21a) is provided which has air inlets 171, 172 from a blower hood 170, extending past the entrance chamber to decroceinating tank 17 (Fig. 3) and opening into the end of conduits 167—167¹ (adjacent to the pulleys 190, 191 for conveying the film), which open at their farther ends into chambers 20, 21¹, respectively. The conduits are provided with windows 172¹ (Fig. 21) through which the films may be observed.

The heating unit, guideways, blowing device, decroceinating tanks, and driers have been described with reference to the single sequence of apparatus and parts which is generally designated R in Fig. 2 and arranged for the printing of the blank in red dye, but as will be readily apparent from the drawings, such parts are shown in duplicate, the elements of the second series being substantially identical with those of the first, for effecting the printing of the blank in green from the green matrix as already indicated and hereinafter to be described. The corresponding parts of the second series of elements are indicated by the same numerals as those of the first, but primed.

As a preliminary step to the operation of the apparatus it is necessary to fill the water tanks 6 and 6¹ and provide a constant circulation of fresh water, preferably maintained at constant temperature therethrough by means of the water pipes 175. It is also necessary to fill tanks 8, 8¹ with water and assure a constant flow through openings 101 and outlets 102 (Fig. 9). The water bath of the dye tank 7 is likewise adjusted and the valves 25 to the water showers 24 and valves (not shown) controlling the water nozzles 76, 77 are opened.

Compressed air is let into pipe 72, and an electric current passed through heating coils 117, if required.

An air pressure of suitable proportions is set up and maintained in the system connected to the openings to the chamber 149, and a hydraulic pressure through inlets 133 to chambers 132. The latter may be connected to a preheated or precooled supply of water for the purpose of circulation, through chamber 132, more accurately to control the temperature conditions during the imbibition, and likewise the water to tanks 6 and 6¹ may be preconditioned. The water in tank 8 is also preferably heated or otherwise treated to expel dissolved gases.

In the practice of the method of the invention by means of the apparatus thus illustrated and described, the (red-dyed) matrix film 3 contained upon the reel 30 is first set in place on bracket 31 and the film passed over pulley 37 and thence alternately over the upper and corresponding lower pulleys 47 in the dye tank 39, over pulley 73, over pulleys 74, 75 in conduit 48, and downwardly and under pulley 91, where it is brought into contact and registry with the upper surface of the continuous belt 11. Here the usual sprocket holes in the margin of the film are passed over a corresponding series of projecting pins provided along the marginal edges of the latter already described.

In passing over the pulleys here employed, the film or composite strip, as the case may be, engages the annular shoulders 51 (Fig. 25) thus leaving both sides of the intermediate portion of the faces of the strip open to free contact with the surrounding medium (liquid or gaseous) but out of contact with the solid parts of the apparatus.

The belt 11 is characterised by being longitudinally non-extensible but flexible and provided with

means (such as the projecting pins already mentioned) for engaging the matrix film as well as the film to be printed.

The belt 11, with the end of film 3 contacting therewith, is next advanced under the pulley 91. Film 2 from reel 320 is then led through tank 6 downwardly over suitable pulleys and into contact with the matrix film 3, the pins upon the flexible belt 11 projecting through the sprocket holes of matrix film 3 being sufficiently long to engage the sprocket holes in the blank film 2. The thus contacting belt 11, matrix film 3, and blank film 2 are next advanced between the pair of compression rollers 9, thence between the second pair of rollers 10, the belt 98 being of such width as to enter between the marginal pins provided upon the flexible belt 11 and thus to force the films into intimate contact with each other, this intimate contact tending to be subsequently preserved by the friction of the margins of the sprocket holes in the films upon the pins of the metal belt upon which they are impaled.

The composite strip is now passed through aperture 104 into chamber 105, in which it passes between compression rollers 107—108, 107a—108a, 107b—108b (Fig. 3), thence over heating unit 117 and between rollers 107c—108c (Fig. 16) and from there along or through the path defined by conduit 116 passing over the larger pulley 12 at the opposite end of the apparatus and back to the entrance end. Here the film blank 2 is separated from the belt and matrix film 3 by passing over pulleys 190, 191, and through conduit 167 to drying chamber 20. (It may be reeled at this point, or, as shown by Fig. 2, passed thence over suitable pulleys, to and through water tank 6¹ and thence through a substantially identical path in the second or green-dyeing unit of the apparatus, in contact with the green-dyeing matrix film 5 and finally to gathering reel 321.)

The matrix film 3 is separated from the belt by passing over pulleys 16, thence into the decroceinating bath 17, under pulley 137, over pulley 138, under pulleys 139 and 140, and thence over the first pulley 146 between the air jets from tubes 159 (Figs. 22, 24) over the upper pulley 146 and thence through the horizontal drying chamber 19 and into vertical drying chamber 20, suitable pulleys being provided as indicated in Fig. 2. Weights 27 are suspended also by means of floating pulleys upon freely depending loops of the film between the fixed pulleys in drying chamber 20 to maintain constant tension thereon. The film is finally gathered upon reel 26.

The flexible belt 11 returns to the starting-point under pulley 13, passes over the upwardly tensioned pulley 14 and under the pulley 15 in water tank 8.

A suitable red or red-orange dye solution is now supplied to dye tank 39 (after threading and adjusting the printing matrix film and blank film through the apparatus as has just been described) by opening valve 62 and subsequently adjusting the same so as to maintain a slight overflow at 63 which may be re-used after adding enough dye to assure uniformity. The green-dye tank 40 is likewise filled with an appropriate green-dye solution which is thereafter circulated in a similar manner by adjusting valve 62¹.

The belt 11 is now driven through the described circuit by positive actuation of the pulley 12. Suitable driving mechanism is also provided which may be advantageously synchronized with pulley 12 for gathering up the matrix film. The latter may be controlled, for example, by movement of the suspended weights 27.

The printed film 2, after leaving the belt 11, may be drawn through its subsequent path through the apparatus by separate means of any suitable sort if one colour only is to be imprinted thereon, or, as in the present instance, may be passed directly to the second or green-dyeing unit and drawn therethrough by the normal operation of the apparatus in the same manner as in the first operation which has just been described and finally rolled up upon reel 321.

When operated in this manner the film blank 2 is continuously drawn through the water tank 6 and thus thoroughly wetted. This tends to soften and also slightly to swell the gelatinous substance of the film, which also promotes its susceptibility to the wetting and absorptive characteristics with respect to dye solutions. Accordingly it is substantially uniformly wet and saturated with water before it enters the water in tank 8.

The matrix film is drawn from reel 30 under slight tension, produced by the friction of brake mechanism 33, over pulley 37 and thence downwardly and upwardly through the red-dye solution in tank 39. By providing an extended path through this solution, the matrix is thoroughly and uniformly contacted therewith. Due to the surface characteristics of matrix films, however, the dye is adsorbed upon the respective areas of the film substantially to correspond to the degree of development thereof. Upon leaving the tank any loosely adhering dye solution is effectively removed by a blast through nozzles 71 which open adjacent to the opposite faces of the wet film. The film then passes through conduit 48 and downwardly between the opposed jets of water from apertures 80 and 81 which thoroughly rinse the film and wash off all the dye solution except that which is specifically adsorbed in accordance with the nature of the surface and developed structure (physical or chemical) thereof which remains associated with the matrix film in proportionate distribution. The film then passes downwardly into the water in tank 8.

By the submersion of the matrix and blank films in water (or other suitable liquid) the wet condition of their surfaces is maintained (as well as of the dye upon the matrix film) and at the same time any entrained or adsorbed air or air bubbles are removed. The matrix strip and blank film may be further cleansed by a jet of fresh water from nozzle 400 (Fig. 9), which agitates the water in tank 8. The surfaces are thus conditioned for effectuating an intimate and uninterrupted contact therewith, which is especially desirable or necessary for satisfactory imbibition. Accordingly, when the belt 11 with matrix film 3 is advanced and blank film 2 brought into registry and contact therewith, and the three strips are carried thence between pressure rollers 9, 10, they are separated only by a continuous film of water which is progressively expelled by the compression applied by the rollers. The wet matrix film and impregnating stratum of dye thereon effects an intimate wetting contact with the film blank such that the dye may be substantially completely transferred to the latter by selective imbibition (*i.e.*, during the subsequent period of traverse of the belt during which such contact between the film surfaces is maintained).

To further perfect this contact, the belt and films pass under the belt 98 which fits between the marginal rows of pins on the belt 11 and progressively forces both films firmly downward over the pins and against the unyielding backing of the belt. As already mentioned, the resulting friction between the pins and sprocket holes of the films effectively retains this relative disposition of the three strips which then pass out of the water tank 8 through aperture 104. At this point some leakage of water is certain to occur, but this is removed through drains 174.

Upon now passing between the spring compressed rollers 107—108, 107a—108a, 107b—108b, the strips are still further compressed and then guided to pass over the heating elements 117 (Fig. 16).

The heating elements may be operated or not, as desired, depending upon the nature of the dye solution, temperature and humidity conditions, and like considerations affecting the condition of the films.

The strips pass between rollers 107c—108c (Fig. 16) and then into and through the conduit 116 supported by plates 136 which in turn rest upon the side walls, the intermediate portion being preferably maintained at a substantially constant temperature, due to the transmission of heat through plates 136 to or from a current of cold water which may be circulated through passages 132.

At the end of the first run of conduit 116 the combined strips pass over driving wheel 12 and thence back through the return of conduit 116 to the pulleys 190, 191. The length of this run is so determined with respect to the operating conditions and the properties of the film, dye, etc., that by the time this point is reached, the originally blank film has substantially completely imbibed the dye from the matrix film and is also sufficiently dry to permit separation therefrom without any tendency for the dye to be redistributed through the film or to be disturbed in the relative values in which it appears upon the film surface.

The matrix film 3, which may retain small quantities of dye in its printing areas or in the sprocket holes, is separated from belt 11 by pulleys 16, and then passes through a decroceinating tank 17, so called, containing a solution of alcohol and ammonia, for example, which rapidly and completely removes such traces of dye from the film. It is then withdrawn by passing over rollers 137, 138, and 139 and passed through rinsing tank 18 containing a constant circulation of fresh water, and thence sent between blasts of air from the opposite slits 162 of blower 144 which effectively wipe off surplus water, the adsorbed water being dried off upon passing through the drying chamber 19 and through the vertical dryer 20. In the latter a plurality of vertical runs is provided to form an extended path, one or more free loops being left in which loose pulleys and weights 27 are suspended which serve to take up and modify the effective tension upon the film throughout the earlier stages of its travel through the apparatus. It is then gathered upon reel 26, which, as already indicated, may be synchronized with the wheel 12 or by the tension and movement of the weights 27, or both. As thus treated, the matrix film is dry so that it may be safely reeled without danger of sticking and substantially entirely free from adhering dye and ready for re-use even after it has been passed through the dyeing and printing steps many times.

Returning to the blank 2, which has now been printed with the red aspect of the final reproduction to be imparted thereto. This film may be passed between air blast nozzles (177) and thence over pulley 191 (Fig. 3) to the extended horizontal drying chamber 167. Here the film passes in the same direction as the current of air from blower 170, finally emerging into dryer 20, through which it may pass. Of course, if only one colour is to be used, it is now finished, but ordinarily it is necessary for effective results to print it with one or more different colours. To this end it may be conveyed to and through the water tank 6¹ of unit G, which again wets it thoroughly, though probably slightly more in the unprinted portions and in those areas in which light shades or tints only have been produced than in the heavily printed parts.

The film is then returned to the entrance end of the unit G (Fig. 2), where it is immersed in water contained in tank 8¹, where it is contacted with the green matrix film 5. In this unit the matrix film 5 passes from reel 30¹ through green-dye tank 40 and thence in vertical runs over pulleys 22 in tank 23 (Fig. 5) before passing through conduit 48. Each run is provided at the top with a water shower 24 which floods the film immediately below it and thus removes excessive and non-uniform accumulations of dye, the wash water draining off at the bottom. Alternatively, the tank 23 may be filled with water which is circulated therethrough. The film 5 then passes through conduit 48 and downwardly into tank 8¹, where it engages the belt 11 and comes into contact with and is accurately registered with the blank film 2 so as to coincide with the complementary images already printed thereon.

After passing through a like procedure to that already described with respect to the red dye (but in which certain changes may be made such as omitting the operation of the heating unit, etc.), the matrix film is drawn through the decroceinating tank 17¹, rinsing tank 18¹, horizontal dryer 19¹ and vertical dryer 20¹, and reeled up at 26¹ ready for repeating the operation by returning the reel to bracket 31. The printed film is now gathered upon reel 32¹ after drying and is ready for use in the usual cinema apparatus for the projection of coloured motion pictures.

After being once "threaded" and used in the manner described, the apparatus may be kept in readiness for immediate operation by attaching a blank film or perforated brass strips to the end of the matrix film and to the end of the film to be printed, which are drawn through the apparatus, thus forming a continuous strip throughout the entire length of the unit when the end of the matrix has reached the gathering reel 26. The same may be done in the green unit.

Upon now starting the mechanism it is necessary only to attach the end of the new matrix film to the end of the metal strip, attach the fresh blank film to the other strip, and pass the strips through the apparatus in the manner described. This draws the matrix and blank films completely through the apparatus. The metal strips are then removed from the reels upon leaving the machine and the matrix and printed films are attached to their corresponding reels, which continue to draw them through the apparatus in the prescribed manner.

If two successive but different matrix films are to be used for printing, the second may be directly attached to the first and a fresh blank film attached to the end of the first blank film and the operation conducted continuously. Such operation will practically require that the same dye solutions shall be suitable for use upon both films, although it is conceivable that the dye tanks might be removed and replaced with others threaded with the new matrix and that such interchange might also be effected with respect to the green-dye tank.

From the foregoing it will be evident that this unique method of interlocking the films against relative movement permits the films to be flexed while held in registered relation to each other so that they may travel to and from rollers or drums or along rectilinear paths, that is approximately straight paths or non-rotary paths, while interlocked in registered contact.

1. Apparatus for printing a cinematographic or like dye-absorbent film from a matrix strip by imbibition (dye absorption) from the strip to the film, having mechanism for bringing the film and strip into face contact and pressing them together, characterized by registering pins 11¹ for holding the films against relative movement while in face contact, the pins being mounted on a flexible strip such as the matrix strip or preferably a separate metallic backing 11 to permit the film and strip to travel along either a straight or a curved path while in face contact.

2. Apparatus according to claim 1 further characterized in that the backing is in the form of an endless belt traversing an endless path along a part of which the film and strip are held in face contact as aforesaid.

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3. Apparatus according to claim 1 further characterized in that the strip and film are fed from the backing at successive locations along the path of the backing.
4. Apparatus according to claim 1 further characterized by means for controlling the temperature of the film and strip while in face contact.
5. Apparatus according to claim 1 further characterized in that the strip and film are brought into intimate face contact while submerged in a liquid medium.
6. Apparatus according to claim 5 further characterized by means for agitating the liquid where the strip and film are brought into contact as by a jet of fresh water from nozzle 400 (Fig. 9).
7. Apparatus according to claim 1 further characterized by means (such as perforated belt 98 as in Fig. 9 or 112 as in Fig. 3) for pressing the film and strip together intermediate the sprocket holes.
8. Apparatus according to claim 1 further characterized by suction openings (such as shown at 83 in Figs. 13 and 14) for removing the liquid squeezed from between the film and strip.

E.P. 319,924. Kienninger, J. F., and Technicolor, 1928.

This patent is complementary to E.P. 307,659. The speed of movement of the films in one of the paths is automatically controlled by the speed of a portion of the blank film outside the said path, so that the films move in synchronism.

E.P. 322,173. Tuttle, B. S., and Technicolor, 1928.

A method of cleaning dye-imbibition films by immersion in a solution of ethyl alcohol and not more than 2 per cent. of ammonia and drying. Alternatively, amines, such as diethyl amine, may be used.

E.P. 344,026. Technicolor Motion Picture Corporation.

Picture band records colours and the sound record is black-and-white whereby colour pictures and records of both high and low acoustic frequencies may be accurately reproduced from the same film.

E. P. 345,986. Troland, L. T., and Technicolor, 1929.

Printing of sound tracks as a matrix relief or a dye transfer therefrom. The dye is confined to the surface of the gelatine so as to improve definition. Contact may be increased in the relief by etching off all gelatine adjacent to the record, leaving bare celluloid which will not imbibe the dye. The sound track is printed from one or more of the matrices bearing the reliefs of the pictures.

E.P. 353,962. Kienninger, J. F., and Technicolor, 1930.

Further additions to E.P. 307,659 concerning alignment of wheels carrying matrix and blank films for imbibition.

E.P. 360,274. Weaver, E. A., and Technicolor, 1930.

The taking filters for colour recording for two- and three-colour films have special transmissions corresponding to the colours reflected from the most prominent objects of the scene. Filters for flesh and foliage are specified, the bands of the two filters being interleaved. For the red-orange filter Eastman Yellow and Acid Rhodamine 3R are used, and, for the green, Uranine and Fast Light Green. Naphthol Yellow, Quinoline Yellow, or Auramine may replace the Eastman Yellow, Rose Bengal may be used instead of Rhodamine, other derivatives of Fluorescein may replace the Uranine, and Patent Blue, Erio

Green, or Guinea Green—the Fast Light Green. These filters give a pale neutral tint for the blue sky, this colour being recorded in equal amounts by the two filters. (*Note.*—It may be assumed that these filters were used by Technicolor for productions such as “Whoopee,” in which two-colour exteriors appeared.)

E.P. 370,908. Troland, L. T., and Technicolor, 1931.

Simultaneously recording tricolour components of a scene on different superposed layers of suitably sensitized coloured emulsions, and subsequently *dissolving off* individually one or more image layers, prints being taken before and after each dissolving step to obtain individual colour records. The layers may have different solubility in the same solvent at different temperatures or in different solvents.

E.P. 374,849. Troland, L. T., and Technicolor, 1931.

Positive imbibition matrices are produced from two-colour records contained at different depths of a single emulsion or in different coatings on the same side of the support by staining the records, printing one record with light transmitted by the other record, and printing the second record by light transmitted by the first record. The colours are not necessarily related to the recorded colours. Thus for two-colour work the colour records are produced in a negative film carrying an emulsion having the outer layer sensitized to warmer colours and dyed orange throughout. The emulsion is exposed through the support, and after development the negative is fixed in plain hypo and washed until free from dye. Both images are then converted into yellow or minus blue, and the warmer image is then converted into magenta or minus green, and separate positive prints are obtained by printing with blue and green light. For example, the images are converted to Metanil yellow and the surface image to magenta by allowing a small amount of acid to diffuse into the film. To facilitate separate treatment of the images the sensitive layers of the negative are preferably separated by a free gelatine layer. Alternative methods of colouring the images comprise: (1) colouring the outer image magenta by limited diffusion, and then converting the other image to yellow by chemical or dye toning; (2) converting both images to unexposed silver salt, exposing and developing one image without the other and utilizing the unexposed image as a mordanting base for a suitable dye, followed by toning of the exposed image.

For three-colour a bipack is used, the front member of which carries an emulsion adapted to record two components from which separate prints are obtained, as described above, the rear member carrying a single emulsion adapted to record the third component, from which a print is obtained in the ordinary way.

E.P. 377,033. Troland, L. T., and Technicolor, 1931.

A silver emulsion for matrix imbibition printing is uniformly hardened before or after exposure, and after development is treated with an agent producing softening in the exposed areas. Hardening agents mentioned are chrome alum, bichromate, formaldehyde, pyrogallol, pyrocatechol, or hydroquinone. The softening process is carried out with oxidizing agents such as ammonium persulphite or mixtures of potassium ferricyanide and potassium permanganate, copper bromide, nitric acid, and sodium perborate.

E.P. 382,320. Troland, L. T., and Technicolor, 1931.

Differential treatment of images obtained in different depths of an emulsion (*e.g.*, colour component images); the image layer is subjected to the action of an oxidizing agent having a certain speed of penetration (*e.g.*, cupric bromide or a solution of iodine in potassium iodide), and the action is interrupted upon reaching the desired depth by a reducing agent having a greater speed of penetration (*e.g.*, sodium bisulphite or ammonia). Following the above action, the lower image can be toned with ferric sulphite or other iron toning solution and the upper image dyed with a dye having an affinity for silver iodide (*e.g.* safranin or fuchsin). The process is applicable for the case of more than two superimposed images.

E.P. 392,785. Troland, L. T., and Technicolor, 1932.

An imbibition matrix relief comprises interconnected image-forming elements of dye-absorbing gelatine embedded in a body of relatively non-dye-absorbing gelatine having approximately the same thickness at any point of the relief, the surface of the relief being substantially smooth. Such a relief is obtained by developing a silver halide emulsion with a hardening developer (*e.g.*, pyrogallol or pyrocatechin) without reducer, and then subjecting it to a controlled oxidation treatment to oxidize the unexhausted developer in such a manner as to produce a body of non-dye-absorbing but relatively soluble gelatine filling the spaces between the particles of developer-hardened gelatine. Oxidation may be effected by vigorously washing in water containing dissolved air, or by oxidizing agents such as potassium bichromate or ferricyanide, oxidation being controlled by regulation of the length and pH of the oxidizing wash, the concentration and pH of the bichromate or ferricyanide, and the pH of the developer. In an example an exposed film is treated for $3\frac{1}{2}$ minutes at 64° F. in a developer comprising

0.8	per cent.	Pyrogallol,
0.3	" "	Sodium Hydroxide,
0.15	" "	Potassium Bromide,
0.15	" "	Ammonium Chloride,
0.02	" "	Citric Acid.

After development the film is passed to a wash-tank through which water is circulated so as to be changed completely in about 10 minutes, the water entering at about 64° F. and with a *pH* of 6.5. The film is treated for 2 minutes and is next treated for 1½ minutes in a bath of ferricyanide of 14 per cent. strength, kept at a *pH* of 3.7 and a temperature of 65° F., which oxidizes any remaining developer and bleaches the silver image. After a further wash for 1½ minutes in water at 65° F. and with a *pH* of 6.5, the film is fixed by treatment in a non-acidic sodium thiosulphate solution of normal strength and then etched by water at 130° F.

E.P. 410,733. Troland, L. T., and Technicolor, 1932.

Grainless gelatine reliefs, suitable for imbibition printing, are obtained from silver halide emulsions of substantially uniform size of grain. To control the gradient of the relief, the emulsion is dyed and may be printed with light of a colour complementary to the dye. In an example a silver bromide emulsion having a grain size of 0.1-0.4 micron is employed and is dyed with a mixture of tartrazine and naphthol yellow.

E.P. 480,173. Technicolor Motion Picture Corporation. Filed August 17, 1936.

Film gate with claw feed mechanism and fixed registering pins. Margins of film confined during exposure and released during film feed.

E.P. 484,411. Technicolor Motion Picture Corporation. Filed November 4, 1936.

Gelatine film blanks for imbibition printing are prepared by treating the blank in a solution of a hardening agent, the *pH* of the film and of the hardening bath having been previously adjusted to produce a *pH* value corresponding to the isoelectric point of the gelatine during the hardening process. The film may be subsequently washed in a bath maintained at the isoelectric point. The process may be used for imbibition printing films for colour printing on a film on which a sound track has already been printed. For example, the sound track is developed in a non-hardening developer (metol) and subsequently washed in water at a *pH* of 7, fixed in neutral hypo solution, and again washed in water at a *pH* of 7. It is then hardened in a solution of chrome alum of 50-52.5 gm. per litre having a *pH* value adjusted to 3.45 by addition of ammonia, and again washed.

E.P. 487,941. I.B. Corporation. Filed December 28, 1935.

See above, page 473.

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E.P. 492,673. Technicolor Motion Picture Corporation. Filed February 12, 1937.

Conversion of plane polarized light to elliptically polarized light in the prism system by the use of quarter-wave plates.

E.P. 496,997. I.B. Corporation. Filed March 10, 1937.

Masking and processing of multilayer films of the Kodachrome tripack type. Compensating the undesired absorption by colouring-matter, for one colour aspect, of light which should only be absorbed by another colour aspect, characterized by forming for one of said aspects an uncorrected (for example, the green aspect) record constituted by light sensitive emulsion, developing a record of the other colour aspect (for example, the red record) to absorb light to which the emulsion constituting the first record is sensitive, and thereafter forming from said light sensitive emulsion record a developable corrected colour-aspect record by exposing it through said developed colour-aspect record in register therewith, said compensating exposure being restricted not to exhaust the light sensitive emulsion forming said first record. The complete job will depict the red colour-aspect of the original by the red light absorption of the cyan colour in one emulsion layer whereas the green aspect is depicted by the sum of the green light absorption of the said cyan record and the green-absorption of the magenta record in a second emulsion layer (Fig. 253).

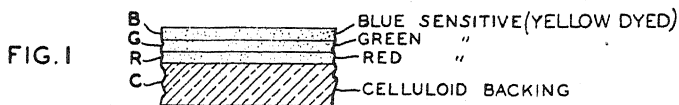
E.P. 536,396. Technicolor Motion Picture Corporation. Filed September 20, 1939.

Compensating background projection prints locally by making a negative with local density, say in the centre, to compensate for "hot spot" projection defects.

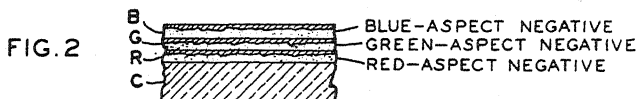
E.P. 536,463. Technicolor Motion Picture Corporation. Filed March 7, 1939.

The travelling monel, or stainless steel, toothed belt on which the Technicolor printing by imbibition is accomplished with such perfect registration of the three printings is made the basis of a unique non-slip continuous printer. The endless belt, carrying its thousands of registration pins, travels around two drums. The printing gates are respectively placed at 9 o'clock on one drum and at 3 o'clock on the second drum. One gate is for sound printing and the other for the picture. The object of the invention is presumably to place the images during printing (of, say, the matrices) in a position identical to that which they are destined to occupy when subsequently used as dye matrices for imbibition on a precisely similar belt (Figs. 254A-B).

I EXPOSE FILM TO SCENE FROM FRONT



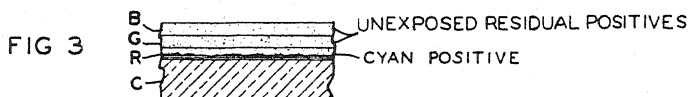
II DEVELOPE NEGATIVES IN RESPECTIVE LAYERS



III EXPOSE R LAYER WITH RED LIGHT THROUGH BACKING C

IV DEVELOPE R POSITIVE IN CYAN (MINUS RED)

V REMOVE DEVELOPED SILVER FROM ALL LAYERS

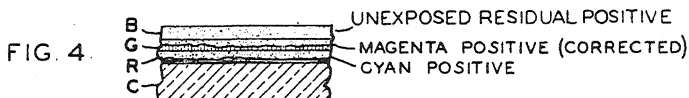


VI PARTIALLY EXPOSE G LAYER WITH GREEN LIGHT THROUGH CYAN POSITIVE AS MASK

VII DEVELOPE G POSITIVE IN MAGENTA (MINUS GREEN)

VIII FULLY EXPOSE G LAYER WITH GREEN LIGHT FROM EITHER SIDE

IX DEVELOPE EXPOSED HALIDE AND REMOVE SILVER



X PARTIALLY EXPOSE B LAYER WITH BLUE OR WHITE LIGHT THROUGH CYAN AND MAGENTA POSITIVES AS MASKS

XI DEVELOPE B POSITIVE IN YELLOW (MINUS BLUE)

XII FULLY EXPOSE B LAYER WITH BLUE OR WHITE LIGHT

XIII DEVELOPE EXPOSED HALIDE AND REMOVE SILVER

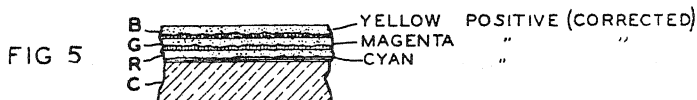


FIG. 253.—E.P. 496,997 of I.B. Corporation. (See p. 490.)

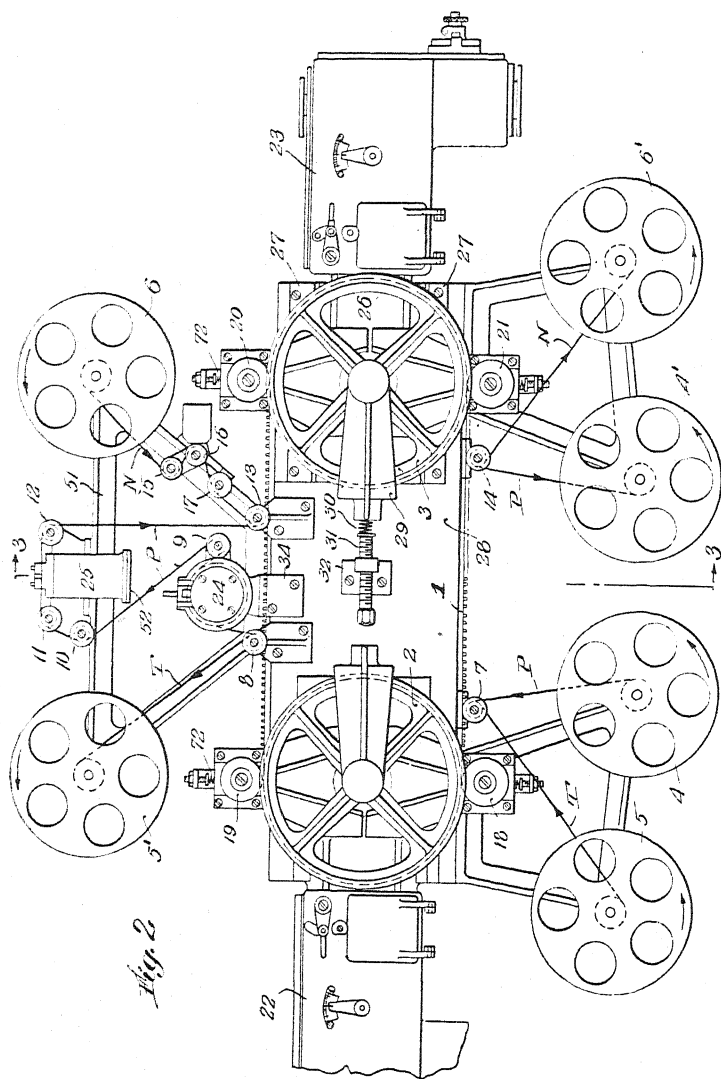


Fig. 254A.—E.P. 536,463 of Technicolor Motion Picture Corporation.

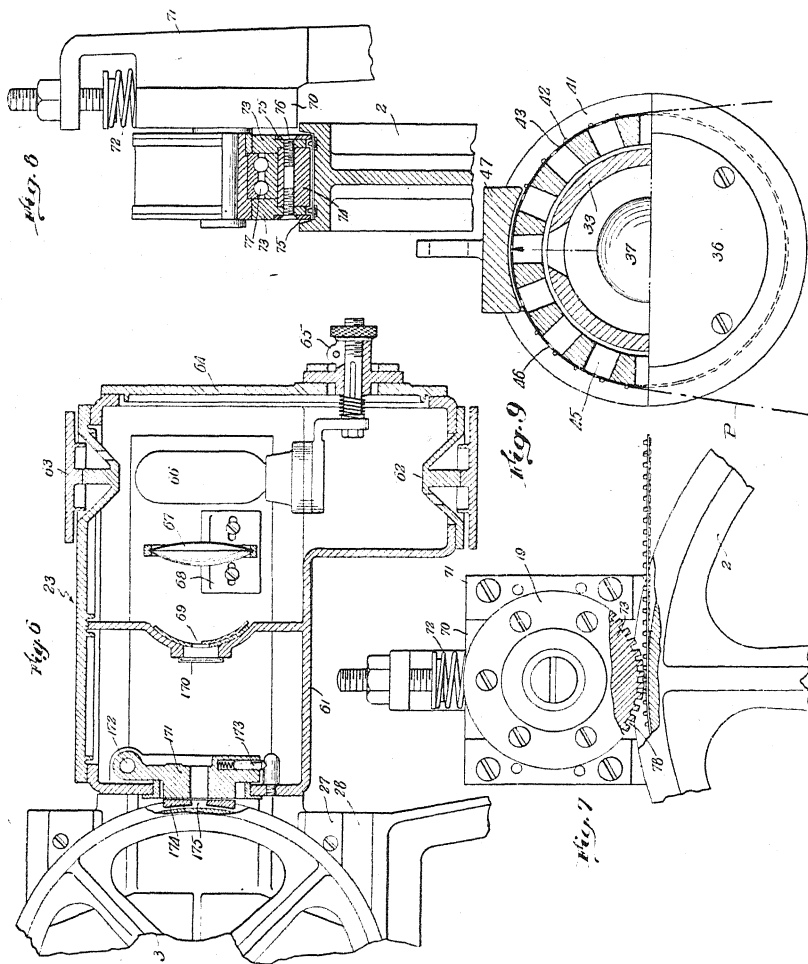
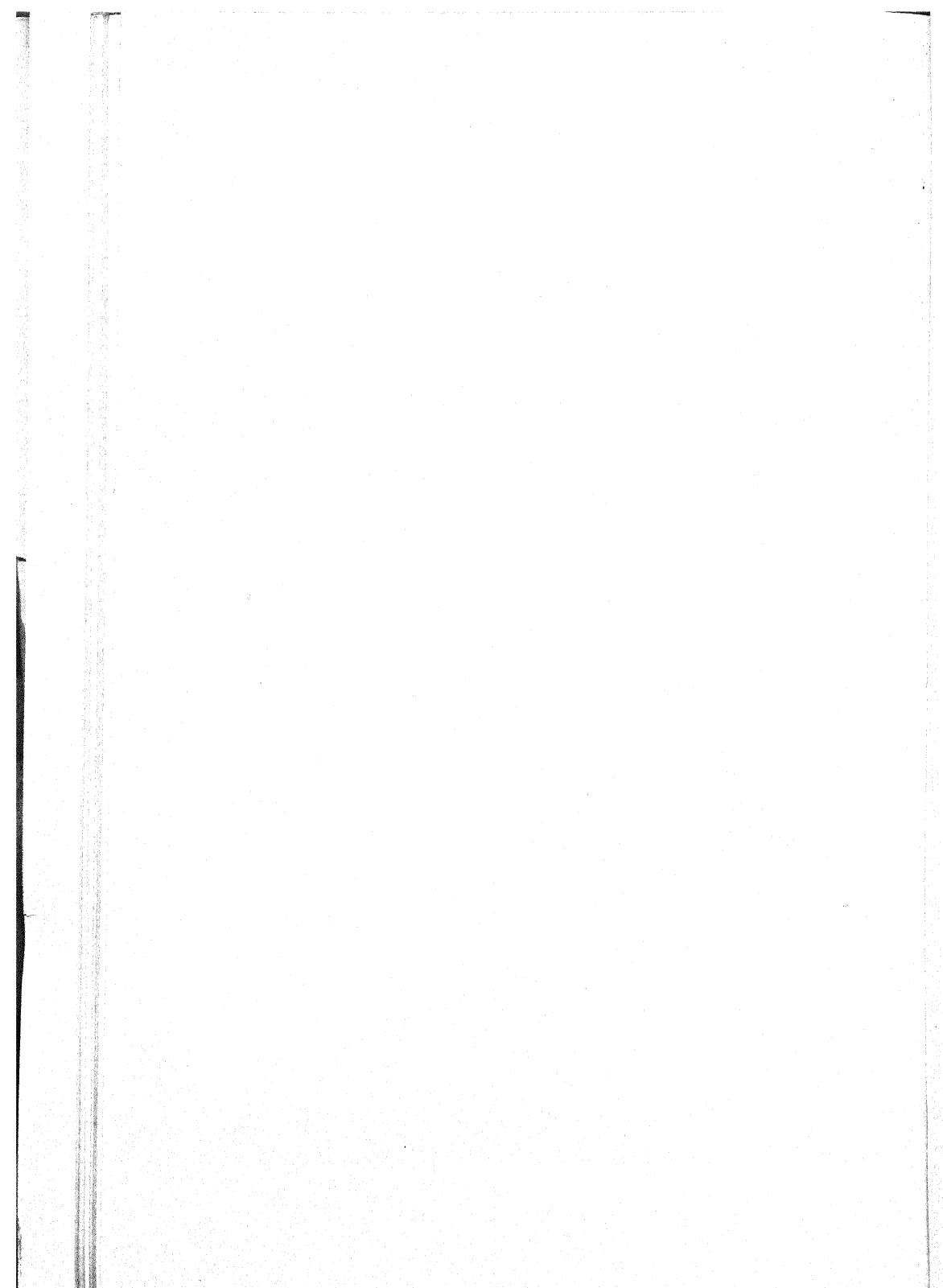


Fig. 254B.—E.P. 536,463 of Technicolor Motion Picture Corporation.



SUBTRACTIVE PROCESSES

E.P. 537,928. Technicolor Motion Picture Corporation. Filed May 5, 1939.

Forming an under-exposed latent image in the film by underexposure to visible light, intensifying the underexposed latent image by flashing the film with infra-red radiation and developing the latent image whereby normal pictures may be obtained with sub-normal exposures.

E.P. 540,296. Technicolor Motion Picture Corporation.

Vapour treatment of cellulose film in the can to renovate or prevent shrinkage consisting of a solvent and plasticizer and a solid agent.
Say

Camphor	..	..	..	15	parts
Alcohol	..	..	..	47	"
Isopropanol	..	..	..	70	"
Dimethyl phthalate	..	..	..	54	"
Tertiary butanol	..	..	..	12	"
Water	..	..	..	90	"

The solidifying agent comprises soap and a fibrous material, such as asbestos fibres.

E.P. 543,113. Technicolor Motion Picture Corporation. Filed June 12, 1940.

Differs from Nos. 307,659 and 353,962 in that the film matrix and blank film are brought into contact under water immediately before being drawn by the registering pin endless monel belt *around the periphery of a drum*, instead of travelling after contact along a horizontal path during the imbibition period. It is claimed that this method increases the accuracy of registration by preventing slippage, and that it eliminates the air space between the films by drawing them together tightly immediately after they have made contact with each other.

E.P. 543,129. Technicolor Motion Picture Corporation. Filed October 18, 1939.

Projection printer film motion. The film is moved from or on to the feeding teeth in a direction parallel to the axes of the teeth, comprising guide means for guiding film along a rectilinear path, feed means having reciprocatory movement lengthwise of said path for advancing the film step by step, said feed means carrying the feeding teeth, reciprocatory means for shifting said guide means in a direction perpendicular to said path whereby to move the film on to and off said teeth, and means for moving said teeth away from said path for threading purposes.

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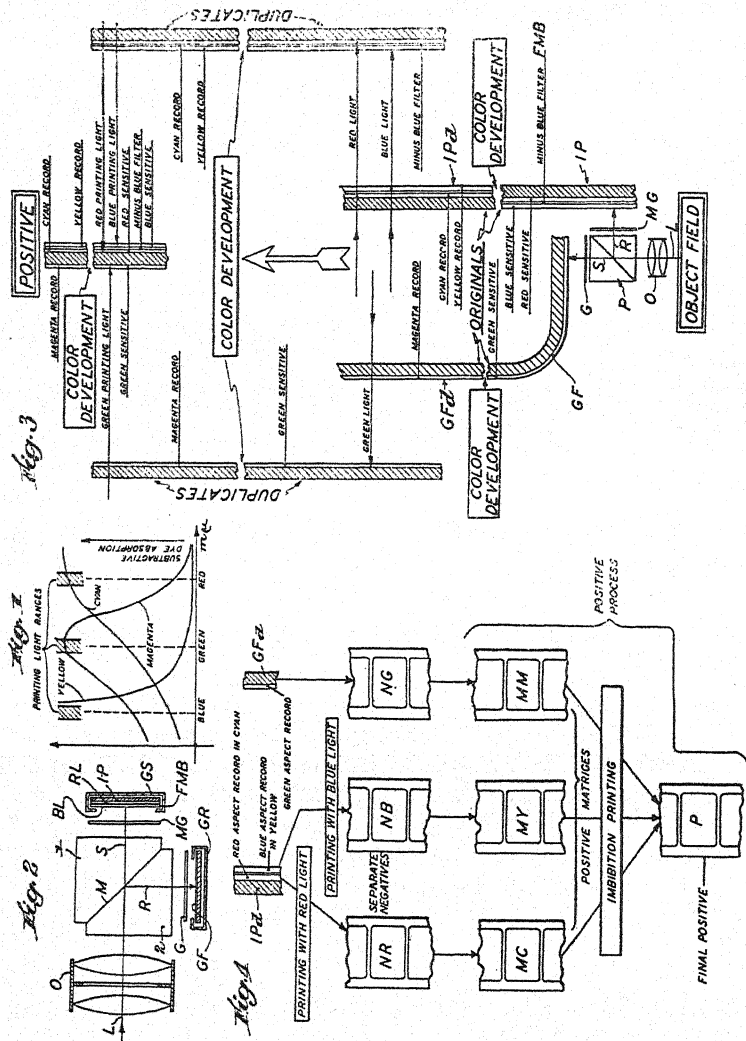


Fig. 255.—E.P. 539,228 of Technicolor.

E.P. 546,667. Technicolor Motion Picture Corporation. Filed May 1, 1940.

Optical printing of mask and picture record by directly projecting the mask record on the picture record, adjusting the image of the mask to obtain exact register, and printing a portion of the picture record with the light imaging thereon the mask record, on an emulsion layer in contact with the picture record. Using a parallel glass plate for the obtaining of register of the single film on the two superimposed films.

E.P. 547,216. Technicolor Motion Picture Corporation. Filed January 16, 1940.

Masked matrices by producing a latent image of a component scene as a background field against a backing, in an unflashed emulsion, which is so sensitized and dyed that its density range corresponds to an exposure range which is a comparatively short intermediate section of the exposure range of the said component scene record by developing the latent image, renovating the gelatine which received an exposure below the said intermediate section, and rendering the remaining gelatine substantially opaque for the light to be used for printing the mask.

E.P. 549,141. Technicolor Motion Picture Corporation. Filed November 15, 1940.

On multilayer film exposing at least two layers to print different colour-aspect records, and simultaneously flashing uniformly, thereby altering the contrast, characterized in that the flashing light reaches the multilayer film by way of a transparent reflector, light of predetermined colour from one direction being transmitted through the reflector to affect one of said layers, and light of different colour from a different direction being reflected by the reflector to affect another of said layers.

E.P. 551,930. Technicolor Motion Picture Corporation. Filed February 7, 1942.

Registration means on a pin-belt printer, the pitch of the teeth being approximately equal to or a multiple of the pitch of the sprocket holes in the seating belt so that the seating belt is drawn towards the register belt by the fanwise movement of the teeth relatively to each other as the register belt is curved, thereby compressing the films into intimate contact.

E.P. 552,008. Technicolor Motion Picture Corporation, 1943.

Making a setting of the Technicolor prism, comprising a method of adjustment affording a precise way of equalizing the size of the direct and reflected images without requiring any delicate adjustment in the camera.

E.P. 553,197. Technicolor Motion Picture Corporation. Filed September 8, 1941.

Making silhouette masks and complementary masks for use in the travelling mask process of composite cinematography characterized in that a plurality of frames are made of a foreground scene having a dummy background during each period of kinematographic analysis having different latent image characteristics as required for the production of silhouette masks and complementary masks by known methods. Said characteristics being obtained by varying the illumination of the

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foreground, said variations being made in synchronism with the intermittent movement, during each period of cinematographic analysis of the camera mechanism by which the said plurality of frames is made.

E.P. 556,631. Technicolor Motion Picture Corporation. Filed June 15, 1942.

Sound tracks and multilayer film. Lacquering sound track area, or picture area, processing the other zone with one or more solutions, removing lacquer with solvent, processing the first zone with one or more liquids the first of which is immiscible with said solvent and intermediate, said last two steps removing said solvent with a solvent miscible with said solvent and also with said one or first liquid.

LACQUER

	%		%
Nitrocellulose (30-40 second) ..	10	Amyl Acetate	8
Ester Gum	5	Ethyl Alcohol	8
Dibutyl Phthalate	5	Toluene	27
Butyl Acetate	23	Carbon Black	2
Butyl Alcohol	12		

E.P. 561,822. Technicolor Motion Picture Corporation, 1944.

A machine for inserting pins in a belt having a series of pin openings characterized by feed means for intermittently feeding the belt along a predetermined path, register means including a pilot pin fitting said openings for accurately positioning the belt between the intermittent feed steps, and means aligning with one of said openings when the belt is positioned as aforesaid for inserting a pin in the opening. (The manufacture of pin belts.)

E.P. 563,737. Technicolor Motion Picture Corporation. 3 pp. Filed in the United States May 4, 1942, and in Great Britain May 4, 1943. Granted August 28, 1944.

A pin-belt machine is described on which films may be registered as for printing from one film to another either photographically or by imbibition. To keep the metal belt from slipping on a pair of end supporting rollers or drums, these supports are perforated and provided with an airtight casing extending about that part of the roller which normally supports the belt. By applying suction to this area, the metal belt is firmly held on the support against slipping.

E.P. 563,834. Technicolor Motion Picture Corporation.

Printing pictures on a dye-absorptive blank by imbibition characterized in that before printing the pictures from the imbibition matrix the blank is treated to produce in it a differential hardness which varies inversely as the density of the colouring matter over the area of the picture.

E.P. 565,384. Technicolor Motion Picture Corporation. 4 pp. Filed in the United States November 11, 1942.

To provide a mask for colour correction in making three-colour subtractive prints, whereby the mask may be exposed with light of any desired spectral range, which may or may not be the same as the range of one of the colour-separation records, and whereby the mask may be processed along with the colour-separation records so that the mask and the colour-separation records will shrink to the same extent and will be available at the same time for printing. A colour-separation latent image and a colour-correction latent image are produced simultaneously by exposing two films to different portions of the same light transmitted along a common optical path and thence along branched paths to the two films respectively. The films are subjected to processing treatment that has a like effect upon their size and that causes the latent images to form colour-separation and colour-correction records of opposite sign. The records are then used in combination to print a colour-corrected picture. For example, a motion picture camera may be employed which has a single, semi-transparent, reflecting surface or beam-splitter, in one beam of which a multilayer film is exposed, and in the other beam of which a panchromatic film is exposed through a yellow filter. The multilayer film is processed to a positive and the panchromatic film to a negative. The two are used in combination to print colour-corrected separation negatives.

E.P. 565,385. Technicolor Motion Picture Corporation. 4 pp. Filed in the United States November 26, 1942. Granted November 8, 1944.

To introduce colour correction and a fade-in at the beginning of a scene, a fade-out at the end of a scene, or a dissolve or wipe at the junction of two scenes in a subtractive colour motion picture print, and at the same time to reduce the number of steps necessary to secure these results or the number of stage-product films required for these purposes, a colour-separation record is formed on one film, a colour-correction record or mask on another film, and successive frames are gradually blocked out throughout a short length at one end of the masking film, and a colour-corrected picture is printed through both of these records. The blocking out on the masking film is preferably effected by dyeing.

E.P. 565,836. Technicolor Motion Picture Corporation. 6 pp. Filed in the United States April 24, 1942. Granted November 30, 1944.

To overcome faulty register due to uneven spacing of teeth on a carrier belt used in the imbibition printing of motion picture films in colour from separate matrices or in the stripping of the several layers of a multilayer motion picture colour record on to separate supports,

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the separate films are registered with the single film on the toothed carrier in such a manner that the same teeth engage the corresponding sprocket holes of each of the separate films and of the single film with which they are registered.

E.P. 565,838. Technicolor Motion Picture Corporation. 5 pp. Filed in the United States April 24, 1942. Granted November 30, 1944.

A method is described for stripping an emulsion layer from one film to another without injuring or distorting the emulsion layer, and for positioning it on the new film in the same relationship to the sprocket holes as on the old film. It affords precise registration and permits the transfer of the layers of a multilayer film after they are exposed and before they are developed. The outer face of the layer to be stripped is stuck to the new base, the adhesion between the layer and the original base is weakened, and the layer and the original base are peeled apart in a single apparatus, the layer being stuck to the new base and at least the latter part of the weakening of the adhesion to the original base being effected while the two bases are travelling in superposition on a carrier which may be endless, and which has a succession of register teeth to hold the bases in register by engaging the sprocket holes of both films.

E.P. 569,426.

A system of printing 16-mm. pairs of images on one 35-mm. film perforated with 16-mm. perforations spaced .95 in. from the edges. The film is slit, after printing and processing, longitudinally along its centre line between the two rows of pictures and trimming off the protective edges. A sound track may be printed inside each row of pictures before the film is slit. The pictures may be formed in relief and the 35-mm. film used as a dye-transfer matrix before or after slitting. The sound tracks may be printed by imbibition or in silver.

U.S.P. 2,352,914. Rackett, G. F. Assigned to Technicolor Motion Picture Corporation. Filed November 15, 1940. Granted July 4, 1944.

A photographic printing apparatus comprises means for guiding a film having two differently sensitive emulsion layers, together with a colour separation record to be reproduced, past a source of printing light, means for projecting the printing light beam through the record towards the film to be printed, and a light-source providing two beams of flashing light of two spectral ranges respectively, there being means in each of the flashing beams for controlling the intensity and spectral range of the beams. Duplicate of E.P. 549,141.

U.S.P. 2,357,924. Andreas, J. M. Assigned to Technicolor Motion Picture Corporation. Filed February 20, 1941.

Photographic colour records printed in superposed relation by the dye-transfer process are corrected for insufficiently strong absorption of light at the far red end of the spectrum by the cyan dye, by printing the magenta and cyan dyes in registered superposition, and by printing the yellow record in a mixture of two dye components, one component absorbing blue light and the other component absorbing deep red light, the ratio of the two components present in all densities of the record being approximately constant and in an amount sufficient to reduce the preponderance of red in the finished record.

U.S.P. 2,363,689. Rackett, G. F. Assigned to Technicolor Motion Picture Corporation. Filed March 2, 1943.

A colour-corrected print is made from a colour-separation record by forming a colour-correcting record of the image on the face of a masking film, forming random irregularities (*e.g.*, by spraying transparent lacquer) on the back of one of the films, and then printing a corrected record on another film. The three films are pressed together in superposition, and the colour-separation film is intermediate between the other two films in back-to-back contact with the masking film.

U.S.P. 2,366,267. Kienninger, J. F. Assigned to Technicolor Motion Picture Corporation. Filed May 1, 1940. Granted January 2, 1945.

In making a print from a masked original film, a projection printer is employed and the masking film is fed through the first film gate and projected by the objective lens on to the second film gate, through which the original film and the print film stock are fed simultaneously and in contact. Thus the printing light passes through the masking film, then through the lens, and finally through the original film to the print stock. The projected image of the masking film is adjusted for magnification with respect to the other two films, but no change is made in the focus of the projected beam. This adjustment may be effected by means of an optically flat glass plate in the light beam which may be inclined at different angles to the optical axis.

U.S.P. 2,369,176. Rackett, G. F. Assigned to Technicolor Motion Picture Corporation. Filed April 24, 1942.

In imbibition printing, or in transferring emulsion layers from one support to another for colour cinematography, the supports on which the transfers are made are successively carried on an endless-pin belt, the same teeth of which engage corresponding perforations of the supports of the several colour components to ensure accurate registry. See E.P. 535,836.

F.P. 880,737. Technicolor Motion Picture Corporation. Filed in the United States February 20, 1941, and in France May 2, 1941. Taken from *Chem. Zentralblatt*, **115**, 632, Part I, 1944.

To remove the red cast from subtractive multicolour pictures, one of the three component images is given an additional absorption for the extreme visible red region. This can be done by using a dye which shows a secondary absorption maximum in this region or by using a mixture of dyes. For example, for the blue image a mixture of brilliant yellow and naphthol green may be used, the naphthol green furnishing the desired additional red absorption. (Translation of the German abstract.) Corresponds to U.S.P. 2,357,924.

F.P. 885,017. Technicolor Motion Picture Corporation. Filed in the United States January 16, 1940, and in France October 30, 1943. Taken from *Chem. Zentralblatt*, **115**, 1360, Part I, 1944.

In a combination taking process a latent image of one of the two elements of the combination (*e.g.*, foreground and background) is produced on a light-sensitive layer which shows marked sensitizing maxima for two colours (*e.g.*, blue and red), while the corresponding element is illuminated with one of the colours. The image so produced is developed in a tanning developer and dyed. In the same way the image of the other element is produced in the other colour. (Translation of the German abstract.)

The Technicolor organization in England has issued the following instructions for the preparation of three-colour cartoon negatives by the successive-frame method.

"The following notes are intended for the general guidance of those producers intending the preparation of cartoon or animated puppet films for reproduction by Technicolor who have not previously submitted tests of their successive-frame negative. They are not intended to serve as specifications for film-strip or slide film material, which requires a different type of procedure in many ways, although the general procedure for the preparation of successive-frame negative for film-strips is closely related."

1. Camera

It is desirable that the negative aperture of the camera used should conform to the recommendations of the Society of Motion Picture Engineers, that is, with an opening 0.868 in. \times 0.631 in. (or 22 mm. \times 16 mm.), placed so that the non-track edge is 0.010 in. from the perforation holes of the film.

It is essential that a camera mechanism of very high precision making use of a register pin movement be employed, since it will be realized that any inaccuracies of positioning the film between successive exposures

in the camera gate will result in colour fringes in the final print. It is also essential that the single frame mechanism by which successive exposures are made should be extremely accurate so that there are no irregularities of the exposure given to the film as each single frame is photographed.

A test of the general suitability of the camera mechanism consists in photographing a chart with a series of ruled lines in the form of a grid, using the negative stock and camera set-up intended for production, but without the use of colour filters. About 100 ft. of negative should be exposed with the chart rigidly mounted, after which the film should be wound back through the camera and re-exposed with the chart again rigidly mounted in a position very slightly displaced from the first position. This negative should then be developed and a print made and projected, or the actual negative itself can be projected. The result on the screen should be perfectly steady, without fluctuations of density or relative movement between the two images of the chart. Variations of density most probably indicate an irregularity of the exposure mechanism while relative movement of the chart images shows that the film registration or film transit mechanism is at fault.

2. Camera Filters

For printing by Technicolor the three exposures must be made through colour filters in the order Blue, Red, Green. This is absolutely essential. The Wratten A, B, C series of tricolour filters or their equivalent should be used and we recommend Wratten filters Nos. 25, 58 and 47. It is very important that care is taken in the mounting and arrangement of these filters in order that the resultant image should conform to our standards of image size and position. Unmounted gelatine filters are most satisfactory from this point of view except under conditions where buckling is likely to occur through humidity changes in the camera room. If the filters are mounted in glass, optical flats must be used and the thickness of each of the three filters should be identical. If the mounting of the filters is insecure or they are allowed to occupy any position other than one strictly perpendicular to the optical axis of the camera the images on the film may be displaced relatively one to the other and this will result in colour fringes through lack of registration in the final print.

To check these points the test outlined in the first section should be repeated with the filters in position, the second exposure of the displaced chart being made with the negative displaced by one frame so as to re-expose each frame through a different filter. On projection of the result the combined image should remain perfectly steady with no relative movement between the two images of the chart. If relative movement is found in this test, although the previous test of the camera mechanism was satisfactory, the filter mounting and alignment must be very carefully checked to ensure that they are exactly perpendicular to the lens axis.

3. Lenses

It is naturally essential that only fully colour-corrected lenses should be used for this type of work and colour prints are likely to be unsatisfactory if the definition of the resultant negative falls below 50 lines per millimetre in any of the three exposures. The maximum photographic sharpness should be obtained for the green filter image in order to obtain the best general definition and equality of size of image, but it is desirable that a sample piece of negative should be submitted for measurement of size, definition and register since not all lenses are perfectly suitable for this purpose. If possible this sample should include an exposure of the standard Technicolor cartoon test chart, which includes a definition fan and register points, photographed so as to appear on the film approximately 1/18th of its original size.

4. Negative and Exposure

Supersensitive panchromatic negative stock closely duplicating that manufactured by the Eastman Kodak Company at Rochester, New York, and perforated with standard Bell and Howell negative perforations should be used. It is important that the tolerance of perforation dimensions recommended by the Society of Motion Picture Engineers (*S.M.P.E.*, 1, 1941, the same as *American Standards Association Z 22*, 1, 1930) should not be exceeded. Kodak negative materials Background -X and Plus -X are both very suitable but care must be taken to avoid grain in the processing of the faster types, such as Super -XX, which is not therefore recommended for normal work.

The developer used should be a fine-grain borax developer and the time of development should be such as to produce a contrast equivalent to a gamma of 0.65 when measured by a diffuse density measuring instrument, such as a Capstaff-Purdy densitometer, on a test strip exposed on an Eastman type IIB sensitometer with the light source adjusted to mean noon daylight. Care must be taken to avoid a high fog level on the negative: with normal gray base negative material the combined base and fog density should generally lie within the range 0.30 to 0.35 and should not be allowed to exceed 0.40.

The level of exposure given should be such that the diffused density of the image of a flat white object on the green filter frame should be between 1.05 and 1.30 after subtracting the combined base and fog density. The actual density read should therefore be of the order of 1.50.

It is important that the balance of exposure through the three filters should be so adjusted that the gray scale of the Technicolor test chart is reproduced as approximately equal density in each of the three frames; the image of a white or gray card which has a density of 1.00 in the frame exposed through the green filter should not differ on the red and blue exposures by more than 0.10 in density.

5. Lighting

The exposure balance referred to above can be achieved either by adjusting the illumination used, making use of colour filters on the lamps if necessary, or alternatively by the use of neutral gray filters mounted in combination with the three colour filters of the camera. If normal type half-watt incandescent lamps are the source of illumination a balanced exposure will usually result from the use of a neutral gray filter of 25% transmission in combination with the red filter, and a 75% transmission neutral with the green filter.

Incandescent lamps run at normal voltages are the most suitable form of illuminant, but care must be taken to maintain the voltage constant, since fluctuations during exposures will cause variations in density or colour in the final colour print.

The use of fluorescent gas-discharge type lamps is not recommended and these should not be used without extensive colour tests, since the deficiency of light in certain parts of the spectrum may cause the unsatisfactory reproduction of some hues.

If coloured lighting is used for special effects, such as moonlight or firelight, it is desirable that the charts should be exposed to normal lighting only.

6. Photography

It is important that at the beginning and end of each scene photographed, a short section, say one foot in length, should be exposed on a Technicolor test chart, so that we can obtain the information on photographic balance, exposure level, development and filter components which is necessary for colour printing. These charts should be stored carefully so as to preserve them in a clean condition and avoid fading.

Each take of every scene should be identified by a card or slate with the name of the production and the number of the scene and take, photographed to length of at least three linear feet (*i.e.*, sixteen cycles of colour exposures). If for any reason, such as camera trouble or incorrect section, it is necessary to stop the camera in the course of photographing a scene and repeat a section of the action, the defective section must be identified by photographing a card marked "Cut Back" on which is written the number of defective frames to be removed before printing.

If a defective scene is later re-photographed, either in full or in part, a new take number should always be used to avoid confusion with previous work.

It is desirable at the end of each scene that photography should be continued for at least a further three linear feet after the last frame of action required in order to avoid the possibility of handling damage during assembly for printing.

It should be noted that as far as possible fades and dissolves should be undertaken in the camera at the time of photography, since although it is possible to make these in successive-frame negative by optical printing in the laboratory the range is necessarily limited to the simplest effects and the process may involve considerable delays and loss of time in the completion of the picture. Wipes, iris masks, and superimposition effects, cannot be undertaken by laboratory work.

7. Despatch of Negatives

All negatives submitted for printing must be clearly identified as developed or undeveloped and should carry the name of the producing company, the name of the subject, an order number, and note of the prints required. Whenever possible a few typical drawings, models, or celluloids, should be supplied as a guide to the colours used.

The negative must be substantially free from scratches, finger prints, abrasions, etc., on the base, or emulsion sides, and should not be cupped or otherwise distorted by drying conditions. To ensure this the rolls must be evenly wound on a suitable centre, carefully wrapped in tissue paper, and packed firmly into securely taped cans preferably containing a small piece of camphor in a cloth bag. Where several sections of negative are wound on one centre the ends should not be clipped together with metal or wire paper clips, as this leads to cinch marks and abrasions during transit.

It is important that rolls of negative should not contain splices, since these have to be made by Technicolor, in order to run satisfactorily through our special printers.

8. Assembly

Where a film has been photographed as a number of separate scenes which have to be put together in the final editing, an assembled black-and-white or colour positive cutting copy representing the finished assembly must be supplied to Technicolor for the purpose of matching the negative. If a black-and-white print is provided it is important that this should have been printed by Technicolor, since only our prints will have the coded edge numbers on them corresponding to those which we put on the negative.

In delivering sound track negatives or prints to match the picture cutting copy, care must be taken to see that they are adequately marked to indicate the synchronization required when printing the two together.

As far as possible, in successive-frame work, reels of assembled negative more than about 1,000 ft. in length in one section should be avoided. This corresponds to a positive print length of about 330 ft., and if the completed picture is greater in length than this it is preferable to use the negative in two parts, and to join the positive prints before despatch. This is because the storage and handling of reels of assembled

negative greater than 1,000 ft. in length is very difficult for use, and the possibility of damage is greatly increased with large reels.

(End of Technicolor instructions.)

BRITISH PATENTS OF TECHNICOLOR

- E.P. 101,972 Successively-exposed image pairs on one film—placing of.
- 127,308 Prism System (Comstock, D. F.).
- 131,422 " " " "
- 132,580 Density control by coloured light (Comstock, D. F.).
- 188,329 Cementing of double width film.
- 194,971 Arrangement of images in prism system.
- 204,034 Differential hardening.
- 209,404 Metal strip backing prior to processing.
- 211,918 Processing by flotation of film.
- 212,134 Prism System.
- 238,445 Registration for cemented films.
- 241,052 Apparatus for processing relief film.
- 263,331 Toning.
- 263,650 Toning, Dye.
- 264,369 Apparatus for printing matrices.
- 270,279 Purification of imbibition dyes.
- 270,280 Hardening of blank for imbibition.
- 288,146 " " " "
- 300,818 Imbibition printing apparatus.
- 307,659 " " "
- 319,924 " " "
- 322,173 Cleaning film matrices.
- 327,633 Skip printer for matrices.
- 343,369 Matrix printing from lenticular film.
- 344,026 Silver sound track and picture dye image (Troland, L. T.).
- 345,986 Dye Toning.
- 347,946 Positive and negative lens combination.
- 349,318 Prism and filter combination.
- 350,112 Prism system.
- 350,320 Achromatic lens system.
- 350,856 Alternate exposure of two colours and a third colour.
- 351,306 Prism divider for three separate films.
- 353,777 Pin Belts, soldering of pins.
- 353,962 Bin Belt arrangements.
- 356,243 Hardening films for imbibition.
- 360,274 Colour filters.
- 370,908 Multilayer film for relief printing.
- 373,429 Prism and film arrangements.
- 374,849 Matrices printed from two colour negatives.
- 377,033 Processing of matrices.
- 382,239 Filters and prism system.
- 382,320 Differential depth toning.
- 385,293 Sensitizing of matrices.
- 392,785 Treatment of matrices.
- 398,339 Beam-splitter camera.
- 410,733 Emulsions for matrix film.
- 475,808 Prism systems.
- 480,173 Camera Gate.

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- 484,411 Treatment of blank.
- 492,673 Prism system and polarized light.
- 534,561 Photometer.
- 536,356 Take-up. Automatically variable tension.
- 536,396 Dark centre print for back-projection plates.
- 536,463 Pin Belt Printer.
- 536,464 Pola screen pre-set light change.
- 536,465 Polaroid screen and light intensities.
- 537,802 Tech. Mot. Pic. Corp. Feeding two films into one gate.
- 537,928 Post Fogging with Infra-red.
- 538,080 View-Finder.
- 538,628 Tech. Mot. Pic. Corp. Masking System.
- 538,744 View-Finder.
- 538,990 Tech. Mot. Pic. Corp. Haze cutting in aerial photography.
- 539,228 " " " " Two films yielding three-colour record.
- 540,296 Solvent mix for treatment of films.
- 540,474 Register Glass for printing.
- 543,113 Imbibition Machine.
- 543,129 Printer Film Feed.
- 544,181 Strengthening film edge.
- 544,749 Film Coupling Device.
- 545,207 Pin Belt. Method of Register.
- 546,667 Composite photography.
- 547,216 Masking by composite matrices.
- 549,141 Flash exposure on Multilayer Film.
- 549,544 Tech. Mot. Pic. Corp. Imbibition printing.
- 550,688 " " " " Modifying spectral transmission of imbibition dyes.
- 551,930 Pin Belt.
- 552,008 Making and setting up of prism.
- 553,197 Composite Photography. Travelling Matte Process.
- 556,631 Sound track lacquer. To protect a sound track image during processing of the colour picture image.
- 561,822 Machine for inserting pins in belts.
- 562,120 Fade device. Shutter.
- 563,737 Vacuum means on Pin Belt.
- 563,737 Tech. Mot. Pic. Corp. Imbibition registration.
- 563,834 Differentially hardened blank.
- 564,532 Back Projection Screen.
- 564,532 Tech. Mot. Pic. Corp. Back projection illumination.
- 564,611 Film Magazine.
- 565,384 Masking in multilayer films used in prism systems.
- 565,385 Masks and fades, etc.
- 565,836 Registering stripping film on pin belt.
- 565,838 Stripping Films.
- 569,426 16-mm. Printing.
- 599,710 Tech. Mot. Pic. Corp. Dye Transfer Machine.
- 600,681 " " " " Blank film incorporating marginal teeth subsequently removable.
- 601,867 Casting a plastic film upon surface of an imbibition matrix and subsequently stripping.
- 604,256 Tech. Mot. Pic. Corp. Producing iron cyanide sound-track in an imbibition film.
- 607,792 Tech. Mot. Pic. Corp. Stable blue-green diazo dyes.
- 612,730 " " " " Printing sound-track for matrix.

SUBTRACTIVE PROCESSES

- 616,168 Tech. Mot. Pic. Corp. Variable speed control for synchronising of imbibition machine.
- 616,178 Tech. Mot. Pic. Corp. Continuous printing of sound-track on film carried by pin-belt.
- 626,319 Tech. Mot. Pic. Corp. Double-coated relief film and fluorescent layer.
- 628,847 Tech. Mot. Pic. Corp. Double-coated relief film and fluorescent layer.

Also see:

I.B. Corporation

- E.P. 487,941 Imbibition printing machine of the pin-belt type.
- E.P. 496,997 Masking and processing of multilayer films of the Kodachrome type.

Eastman Kodak

- E.P. 574,138 Apparatus for stripping single layers of a multilayer film to a new film carrier.
- E.P. 574,139 A multilayer film, the layers of which may be stripped.

U.S. Technicolor Patents (partial)

- 1914 1,196,080
- 1915 1,390,983
- 1916 1,453,325
- 1916 1,493,246
- 1917 1,541,315
- 1917 1,570,809 Film treatment (W. B. Westcott)
- 1917 1,573,595 Dye composition (E. J. Wall, H. Kalmus, etc.)
- 1917 1,573,596 Colour sensitizing (E. J. Wall, H. Kalmus, etc.)
- 1921 1,583,108 " " (J. A. Ball).
- 1922 1,596,808 " " (D. F. Comstock)
- 1923 1,607,440 Film treating apparatus (D. F. Comstock).
- 1921 1,677,309 " " " (L. T. Troland).
- 1925 1,677,310 " " " " "
- 1923 1,696,809 (D. F. Comstock).
- 1927 1,707,695 (L. T. Troland and J. Whitney).
- 1929 1,707,699 (W. E. Whitney.)
- 1927 1,707,710 Imbibition Machine (D. Comstock).
- 1925 1,716,989 Registration for printing (L. T. Troland).
- 1926 1,807,805 Imbibition printing (B. Sugden and B. S. Tuttle).
- 1929 1,821,680 Multilayer film (L. T. Troland).
- 1929 1,844,377 Optical system (L. T. Troland).
- 1928 1,860,912 Dyeing films (L. T. Troland).
- 1929 1,871,649 Colour Camera (J. A. Ball).
- 1927 1,873,259 " " " "
- 1928 1,889,030
- 1929 1,900,140 Imbibition printing (B. Sugden and B. S. Tuttle).
- 1931 1,919,673 Imbibition Reliefs (L. T. Troland and W. S. Eaton).
- 1931 1,923,764 Reliefs (L. T. Troland).
- 1929 1,924,890 " " " "
- 1929 1,924,901 Apparatus (J. A. Ball).
- 1931 1,926,255 " " " "
- 1929 1,928,709 Multilayer Film (L. T. Troland).
- 1929 1,928,714 Pin-belt (J. H. Whitney).

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1934	1,957,128	Beam-splitter prism and view-finder (J. A. Ball).
1930	1,974,935	Lacquering (L. T. Troland).
1934	1,978,979	Optical means for compensating distortion when combining key and colour print (J. A. Ball).
1933	1,993,576	Monopack (L. T. Troland).
1930	2,013,116	Matrix (L. T. Troland).
1934	2,046,320	Hardening gelatine (— Barbank).
1933	2,068,879	
1937	2,072,091	The Technicolor Camera (J. A. Ball and G. F. Rackett).
1934	2,079,470	
1937	2,085,877	Sound Records and Imbibition (L. T. Troland).
1937	2,085,878	"
1935	2,147,683	Comstock and Westcott Inc. ("I.B." Machine).
1939	2,182,142	Prism and Polarizer.
1940	2,189,932	Prism (J. A. Ball and W. E. Pohl).
1940	2,189,933	Prism (J. A. Ball and W. E. Pohl).
1942	2,413,468	Colour Masking using integral tripack and bipack in a beam-splitter (G. F. Rackett).
1945	2,444,786	Endless belt printer (G. F. Rackett).
1945	2,444,785	Projection sound-track printing (G. F. Rackett).

Remarks

Considering the patent history of Technicolor as a whole, we are able to follow the evolution of the present process very clearly. We can see how the experience gained during the period when cemented dyed reliefs were being used must have prepared the way for the decision to use such reliefs for imbibition printing instead of using the dyed relief itself as the final product. A cemented pair of films must have been very unsatisfactory as a finished film. No doubt contraction troubles would have been experienced as the film aged, and projectionists would have experienced difficulty in focusing owing to the buckling of the film. It is interesting to observe the way in which various prism systems of some complexity had to be rejected in favour of the simple block of two cemented 45° prisms.

The class of colour obtained is recognizable *Technicolor colouring*. Indeed, in a way, it has the same result as the specialized technique of a painter which is the outcome of personal methods of pigment mixture and brushwork, the subtleties of which often defy analysis, but the effect is unmistakably apparent in a given artist's work. We can already say of colour film processes that they have a look of "Technicolor," by which must be meant a peculiar quality of colour due to the limitation of all colour tones to a restricted region. Probably art directors of the near future will be able to choose between several equally good processes, their choice finally being dictated by consideration of æsthetic taste alone, based upon an individual preference for the colour character of a process. It remains to be seen whether a tendency to stylization or conventionalization due to any inherent limitation in a process will be a valuable factor or otherwise.

Considered as a technical achievement, the Technicolor process is a monument to the unswerving determination of the group of technicians responsible for its development. They must have encountered immense difficulties. Anybody who has ever attempted to make a colour print by imbibition must realize the tremendous task with which these men were faced. If the various alternatives are examined as they must have presented themselves in the late nineteen-twenties, it seems that imbibition is almost the last method which would have been chosen. Our unstinted admiration should be accorded to Dr. Kalmus and his brilliant associates (6).

TECHNICOLOR PATENTS FOR OPTICAL SYSTEMS, ETC.

(Partial List)

E.P. 101,972	..	Westcott, W. B., and Technicolor	1915
E.P. 127,308	..	Comstock, D. F.	1917
E.P. 131,422	..	Comstock, D. F., and Technicolor	1918
E.P. 194,971	..	" " " "	1922
E.P. 212,134	..	" " " "	1923
E.P. 347,946	..	Ball, J. A., and Technicolor	1930
E.P. 350,112	..	Troland, L. T., and Technicolor	1930
E.P. 350,320	..	Ball, J. A., and Technicolor	1930
E.P. 351,306	..	" " " "	1930
E.P. 373,429	..	" " " "	1931
E.P. 382,239	..	" " " "	1931
E.P. 398,339	..	" " " "	1932
E.P. 475,808	..	Tech. Mot. Pic. Corp. Prism System (earlier)	1936
E.P. 536,465	..	" " " " "Polaroid" Screen and Light Intensity	1939
E.P. 538,080	..	Tech. Mot. Pic. Corp. Viewfinder	1940
E.P. 538,744	..	" " " "	1940
E.P. 552,008	..	" " " " Prism adjustment	1942
U.S.P. 1,390,983	..	Comstock, D. F., and Technicolor	1921
U.S.P. 1,451,325	..	Ball, J. A., and Technicolor	1923
U.S.P. 1,493,246	..	Comstock, D. F., and Technicolor	1923
U.S.P. 1,541,315	..	Ball, J. A., and Weaver, W. V., and Technicolor	1925
U.S.P. 1,738,095	..	Tech. Mot. Pic. Corp. Prism System (earlier)	1925
U.S.P. 2,072,091	..	The Technicolor Camera. (Ball, J. A., and Rackett, G. F.)	1937
U.S.P. 2,182,142	..	Prism and Polariser. (Ball, J. A.)	1939
U.S.P. 2,189,932	..	Prism. (Ball, J. A., and Pohl, W. E.)	1940
U.S.P. 2,189,933	..	" " " " " " "	1940

References

- (1) KELLEY, WILLIAM V. D., *Journ. Soc. Mot. Pic. Eng.*, **10**, No. 27, p. 238.
Imbibition Coloring of Motion Picture Films.
- (2) IVES, F. E., *Journ. Soc. Mot. Pic. Eng.*, **10**, No. 25, p. 74. Ives claims that the dye imbibition process of Technicolor is substantially the method described in his U.S.P. 1,186,000, 1925.

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- (3) WALL, E. J., *The History of Three-Color Photography*, p. 356.
- (4) WALL, E. J., *The History of Three-Color Photography*, p. 635.
- (5) DEBENHAM, W. F., *Brit. Journ. Phot.*, **37** (1890), pp. 516, 542.
Kreutzer's *Zeitschrift für Photographie*, **3** (1861), p. 182.
- (6) TROLAND, L. T., "Some Psychological Aspects of Natural Color Motion Pictures," *Journ. Soc. Mot. Pic. Eng.*, **11**, No. 32 (1927).

See also:

- Report of the Color Committee : Journ. Soc. Mot. Pic. Eng.*, **16**, No. 2 (1931), p. 219, and **18**, No. 6 (1932), p. 792.
- (7) KALMUS, H. T., "Technicolor Adventures in Cinemaland," *Journ. Soc. Mot. Pic. Eng.*, **31**, No. 6 (1938), p. 564.
- HOUSLER, J., "Technicolor Photography under Water," *Amer. Cinemat.*, **30**, 4 (April 1949), p. 122.
- HANSON, W. T., and RICHEY, F. A., "Three-Color Subtractive Photography," *Journ. Soc. Mot. Pic. Eng.*, **52**, No. 2 (Feb. 1949), p. 119.

Thomson Color

(Paris)

Camera.—The original record is said to be made on lenticular film.

Printing.—Positive separations are made on panchromatic double-coated film by optical printing direct from the lenticular film. The printed images on either side of the double-coated film are toned respectively yellow and cyan with thio-indoxyl and ferricyanide. One side is subsequently re-emulsioned, exposed by optical printing to the appropriate lenticular element, developed, and nickel-toned magenta (nickel dimethylglyoxime).

CHAPTER 5

Colour-Camears and Beam-Splitting Systems

Attempt the end and never stand to doubt; Nothing so hard but search will find it out. HERRICK.

THE early attempts to obtain several images of the same subject for the purpose of recording three-colour negatives all indicate an apparently wilful disregard of elementary optical laws. Patent after patent proposes the use of several lenses side by side, or one above the other, or in trefoil arrangement, without any auxiliary optical element being introduced to correct the inevitable parallax which must then occur. Du Hauron himself proposed to use three lenses side by side (1), but he was quite aware of the existence of parallax error. Such parallax is eventually visible in the final colour picture as a coloured fringe, which is due to the lack of geometrical coincidence between the different points in various planes of the subject as viewed from two or more angles from which the respective colour records were photographed. This fundamental defect is made clear to the non-technical by a simple experiment. Cover the left eye, and with the right eye note the position of some object in the foreground (a telegraph pole, for example) with relation to some distant object; then, without moving the head, cover the right eye and with the left eye note the relative positions of the two points once again. They will be found to have altered their relative positions with respect to each other to a marked extent. The parallax fringe around any object when the separate images are superposed in a completed colour picture is given by the formula (2):

$$\text{Parallax} = \frac{\text{Focal Length of Lens} \times \text{Lens Separation}}{\text{Distance of Object}}$$

CLASSIFICATION OF BEAM-SPLITTING SYSTEMS

1. One Lens. Beam divided Once or Twice between Lens and the Film.

- A. PRISM BLOCK. For two gates at right angles to each other. Single film in one gate and bipack in the other for three-colour; or a single film in each gate for two-colour. Semi-reflecting surface on diagonal plane of prism cube.
- B. PRISM BLOCK. For three gates and three separate films.

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- C. ROTATING MIRRORS. For reflection to two or more gates.
- D. REFLECTOR OR REFLECTORS. Images of standard dimensions disposed vertically one above the other on one film support.
- E. REFLECTOR OR REFLECTORS. For two gates or three gates. (These might be pellicles, for example.) One film in each gate.
- F. REFLECTOR OR REFLECTORS. For single gate. Beam divided to expose front and back of film simultaneously.
- G. PRISMS, REFLECTOR, OR REFLECTORS. For two or more sub-standard images on one normal frame.

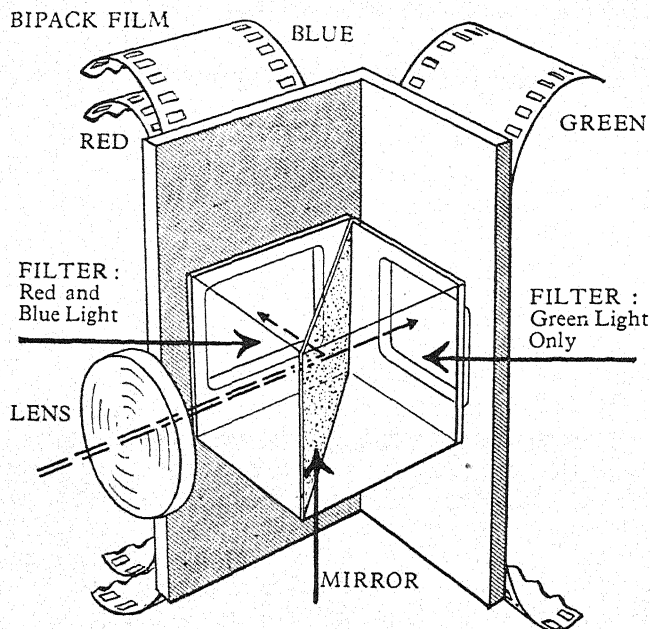


FIG. 256.—Technicolor Beam-Splitter according to E.P. 398,339 and E.P. 373,429.

2. Two or More Lenses without Beam-Division.

Lenses generally sawn off to bring axes closer together.

3. Two or More Lenses behind a Prism System for Beam-Division, or behind a Partially Reflecting Mirror or Mirrors.

- A. Disposed vertically one above the other. Images of standard dimensions, necessitating a pull-down of two or three frames for each exposure. Two-lens systems used with bipack will provide three-colour negatives in each pair of frames.

- B. Disposed horizontally for two or three films, each in a separate gate but in the same plane—*e.g.*, the films are run side by side.
 - C. Disposed horizontally, the images being recorded on extra-width film.
 - D. Two or three pictures of substandard size in the space of one normal frame.
 - E. Two pictures in the space of one normal frame, but their axes turned lengthwise to the film.
 - F. Two images of normal size disposed vertically one above the other. Pull-down normal and each picture exposed twice—*i.e.*, once in each gate.
 - G. Disposed at 90° to each other, or at some other angle. Separate gates and normal pull-down.
 - H. Rotating mirror divider in front of two or more lenses.
4. **Two or More Lenses behind a Negative Divergent Lens. The Positive Lenses photograph a Virtual Image produced by the Negative Lens.**
 5. **Two or More Lenses behind Inclined Glass Plates.**
 6. **Two or More Lenses behind a Large Positive Lens.**

CLASS 1. One Lens. Beam Divided Once or Twice between Lens and the Film.

1A. PRISM BLOCK. *Part of beam reflected at right angles to the axis.*

The Technicolor camera belongs to this category. E.P. 398,339 describes a method of mounting a prism block in such a way as to permit removal and replacement without disturbing the adjustment for image-positioning. Obviously this patent covers only one of many possible devices for accomplishing a similar end. E.P. 350,320, 1930, proposes to achromatize the lens system for the red and green only (*e.g.*, the two colours of longer wavelength).

In E.P. 373,429, 1931, Technicolor have patented one given arrangement of bipack and single film used respectively in two gates. The patent claims an important advantage in exposing the red and green record in separate positions with respect to the dividing beam—*e.g.*, that the red and green records should not be provided by the bipack as usual in two-colour systems, but that the bipack should record the blue in front and the red behind. By this means it is possible to record both the red and green records on the same emulsion (panchromatic), whereas it would not be possible to employ a panchromatic emulsion as the front film of a bipack. In the words of the patent:

By forming on these like emulsions the two images which contribute mainly to building up the gradation, or, in other words, supply the "body," or "substance"

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of the final picture (the gradations of the yellow positive being rather weak), and which must therefore be carefully balanced in exposure and development (e.g., the red and green records), the desired balance may be obtained uniformly and with facility.

In the same patent a fourth "key" print is described (see 14, Fig. 257). This may be a panchromatic emulsion, and it is to be coated with a green filter on its surface. A yellow filter is placed at Y to cut off blue from both emulsions. Emulsion 14 would be a record of red and green light only. The patent states that the black key print is to have a gamma of unity, and that this emulsion may be used to print the sound and the black key print simultaneously, a gamma of one being desirable for sound record development. This patent would seem to reserve to Technicolor the use of the "classical" bipack in conjunction with a single film in any beam-splitting system of the type described in E.P. 398,339.

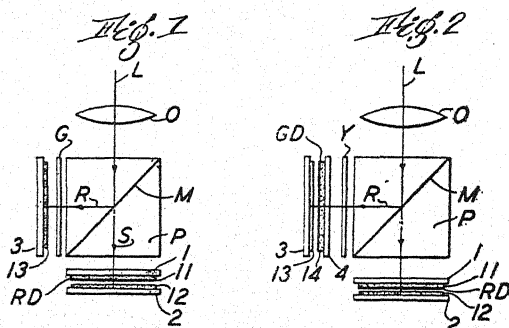


FIG. 257.—Technicolor, E.P. 373,429.

In E.P. 382,239 Technicolor describe a lens system to be used in conjunction with the same arrangement of films as in the above patent 373,429, and which has equal foci for the red and blue bipack records and maximum chromatic correction for the single green-recording negative. A lens system is employed which has a secondary spectrum as shown in Fig. 4 (Fig. 258), in which the derivations of the foci for the various wavelengths of the spectrum, from an arbitrarily selected focus, are plotted against the wavelengths, the principal colour ranges also being indicated in this diagram. From the curve it can be seen that the green range has a substantially horizontal tangent to which each point of the range of the curve is very close, so that the record of this range has an approximately perfect chromatic correction. The fact that the red and blue ranges are not so well corrected is of minor importance, since these ranges do not contribute largely to the definition of the positive colour reproduction. However, the average foci, or the foci of the centres of these marginal ranges, substantially

coincide, resulting in substantially identical focal distance for the blue and red records (the bipack). The fact that the foci for the green range on the one hand, and the red and blue ranges on the other hand, are not equal is of little consequence, since this irregularity can be easily adjusted.

Fig. 1.

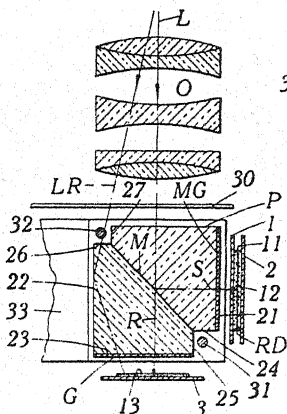


Fig. 2.

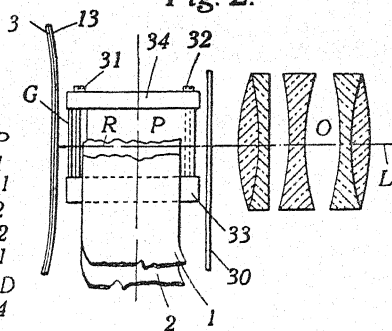


Fig. 3.

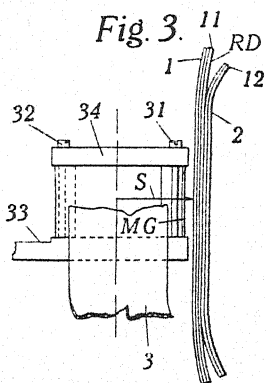


Fig. 4.

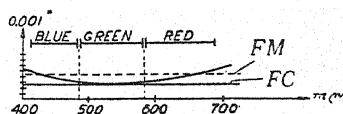


Fig. 5.

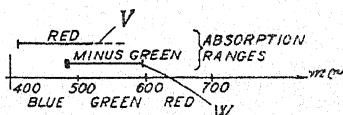


FIG. 258.—Technicolor, E.P. 382,239.

The same patent describes methods for avoiding scattered light in the prism system. A minus-green, or magenta, filter is placed in front of the bipack. This is said to even out the inequalities in the transmission of the red filter which is coated on the surface of the front film of the bipack.

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There is a tendency in prism systems of this type for the film in each aperture to reflect light of a colour to be recorded at that aperture, and this light may fog the film in the other aperture. This fogging tendency is most pronounced at the sides of the apertures which are close together—namely, near the edge formed by prism faces 21 and 23 (Fig. 258). Furthermore, the prism faces reflect light, as indicated by the dotted line LR. The green light which is reflected from the film 3 is effectively excluded from the other aperture by minus-green

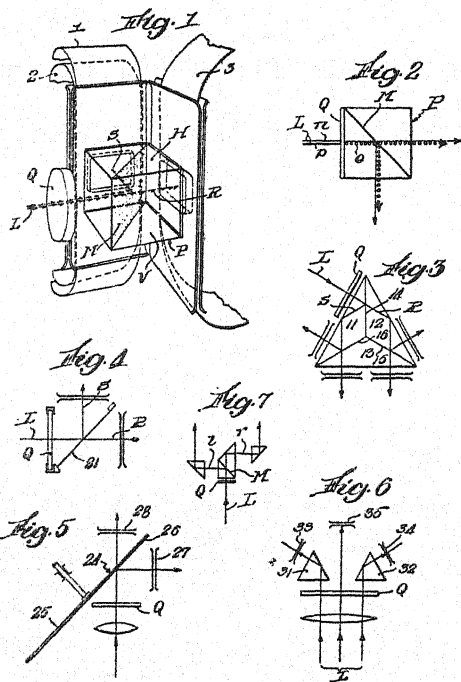


FIG. 259.—Technicolor, E.P. 492,673.

filter MG, whereas the minus-green light reflected from film 1 is eliminated by green filter G. In order to shield the apertures against the especially pronounced reflection in the corner between faces 21 and 23, this corner is made opaque either by blackening the adjacent marginal parts of 21 and 23, or by making the margins of the mirror plane M opaque, or, as shown in the diagram, by providing a notch with blackened faces 24 and 25. In order also to exclude the light reflected at surface 22 (as indicated by ray LR) another opaque edge, or notch, with blackened faces 26 and 27 is provided. The claims in this patent are:

1. The art of colour photography, as claimed in E.P. 373,429, characterized by the use of a red filter between said front and back emulsions, and a minus-green filter in front of both emulsions.

2. The use of means for obstructing from each aperture light reflected from the region of the other aperture.

3. An optical system having substantially equal foci for the red and blue records which are superposed at one aperture, and maximum chromatic correction for the green record at the other aperture.

In E.P. 492,673 Technicolor deal with the elimination of polarized light in a prism system. It is a matter of fact that precisely the same means had been employed by the writer some years *previously* for the Bellingham and Stanley prism described under Class 3D (see page 538). The intensities of the component beams are made independent of the proportion of plane polarized light in the incident beam by a compensating element which converts the light into elliptically (including circularly) polarized light before striking the reflector. As shown in Fig. 259, a prism P divides an incident beam and a quarter-wave plate Q converts any plane polarized light in the beam L into elliptically polarized light.

The patent contains a good description of precisely the effect which the writer encountered. To quote the patent:

When photographing colour-separation records with motion picture cameras employing a light splitter, it was frequently found impossible to maintain the theoretically and experimentally predetermined ratio of light division; for example, the recordation of certain highlights would vary so much that, in the final print, they appeared at one time decidedly green, and then again reddish. After considerable experimentation it was determined that the printing process was not the cause of the trouble, but that the transmission-reflection ratio of the light divider varied. Further research led to the conclusion that the difficulty was due to the fact that the light reflected into the camera from most objects is more or less polarized, and that the effect of the reflector used for dividing light beams of this nature varies considerably with the ratio of incident unpolarized and polarized light respectively and the characteristics of the polarized light itself.

Designers of beam-splitters had better be warned that this effect is almost bound to occur, and there are not many other ways of solving the problem.

Systems of the kind described in Technicolor patents E.P. 131,422, 194,971, 212,134, 350,112, etc., in which a prism system with several reflections is situated between the lens and the film, all suffer from the defect of requiring too long a path to make feasible the use of a short-focus lens such as 40 mm. or 50 mm., which is essential in practical studio work. The angular field of such a lens will be at least 30°, and it is easy to see that none of these systems would be workable.

Technicolor patent E.P. 349,318 (see Fig. 260) is interesting in that it reveals a method of obtaining three-colour records on two films side by side, or upon one film moved two frames at a time. A filter-disc containing primary blue-green and yellow filters is rotated in

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front of the prism, behind which the filters are respectively magenta and green. The front half filter used successively with the rear pair gives alternately:

<i>Front Filter.</i>	<i>Back Pair.</i>	<i>Records.</i>	<i>Frame.</i>
(Minus-red) Blue-Green	Magenta (Minus-green)	Blue	1
	Green	Green	2
(Minus-blue) Yellow	Magenta (Minus-green)	Red	3
	Green	Green	4

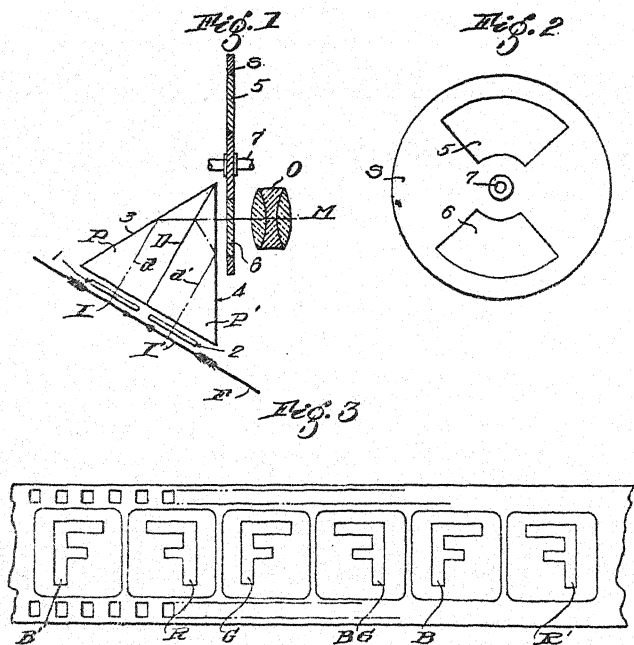


FIG. 260.—Technicolor, E.P. 349,318.

In the patent the statement is made that:

In the case of rapidly moving objects pictures formed through the filters 5 and 6 at successive intervals of time will not register precisely, resulting in a tendency towards colour fringes; but by taking the red and green records simultaneously they will register exactly, and when using only a single additional colour such as blue, fringes will not be noticeable for the reason that the blue record, which is yellow in the final picture, does not contribute largely to the definition of the picture.

The above method necessitates exposure at 48 frames per second in order to register twenty-four complete colour records. With a more satisfactory type of prism this would be a method worth further development. No bipack is to be used. The claims in this patent are as follows:

1. The method of making cinematographic films of the type having three or more series of complementary records, representing different colour aspects respectively, which are to be superposed in subsequent printing or projecting operations, by exposing different records through different filters which obstruct different components of the light respectively, characterized in that one filter functions simultaneously in conjunction with each of two other filters.

2. In that two filters function alternately in conjunction with each of said two filters.

3. Film having three series of records of the object field made along two light paths which comprises simultaneously exposing two of the records along the two paths, each record being exposed through two filters simultaneously, removing one filter from one path and subsequently exposing another record along that path.

4. Simultaneously with the last exposure another record is exposed along the other path, said last filter having been replaced by another filter.

5. An objective, means for dividing light from the objective along branched paths, a filter in each of the branched paths, and a third filter moving into and out of the path of the light before reaching said branched paths.

6. Apparatus according to Claim 5, further characterized by a fourth filter moving into and out of the path of the light before reaching said branched paths alternately with said third filter.

E.P. 475,808 describes a similar light-dividing system which would give rise to innumerable ghost images almost impossible to eliminate. It would be interesting to know whether this arrangement was ever tried. It consists of a prism element receiving the incident light and forming with at least two additional prism elements at least two partly reflecting surfaces inclined to each other, at least one element having a totally reflecting surface inclined to the partly reflecting surfaces for deviating a component beam coming from a partly reflecting surface. The form shown in Fig. 261 (Fig. 1) consists of three similar right-angled prisms 1, 2, 3 placed in contact with each other, the contact surfaces 16, 17 being rendered partly reflecting. A beam R incident normally on the surface 5 of the prism 1 is partly reflected at the surface 16, the reflected beam A being totally reflected at the surface 5 to emerge normally from the surface 11. The beam B transmitted by the surface 16 is again divided at the surface 17, the beam C reflected by the latter surface emerging from the surface 12, while the transmitted beam D emerges normally from the surface 13. In Fig. 261 (Fig. 2) the prism 3 is omitted and the prism 2 is divided into two prisms 32, 33 having a partly reflecting contact surface 37. In this form, total reflection occurs at the surfaces 5, 36. As shown in Fig. 261 (Fig. 3) the images, *a*, *c* may be recorded on a double-width film W moving in a direction parallel to the apex line of the prism combination, the image *d* being recorded on an ordinary film F also moving parallel to this line. Alternatively, as in Fig. 261 (Fig. 2), the images *a*, *c* may be formed on successive spaces of an ordinary film 43 moving at right angles to the apex line, the film 44 also moving at right angles to this line. Fig. 261 (Fig. 4) shows a system producing four images and consisting of three similar isosceles prisms 61, 62, 63 placed in contact to form a combination of equilateral

triangular section, the contact surfaces 64, 65, 66 being partly reflecting. The paths of the rays forming four images k, m, n, p , are clear from

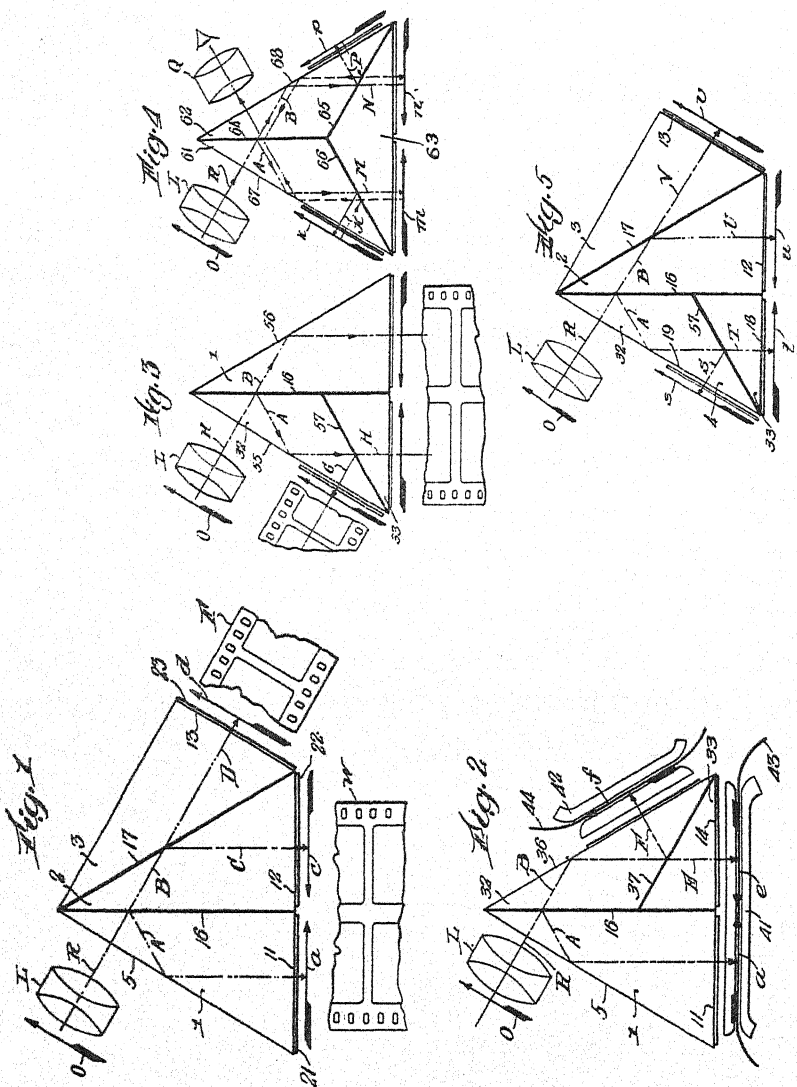


FIG. 261.—Technicolor, E.P. 475,808.

Fig. 261 (Fig. 4). With this form the images can be viewed simultaneously in superposition by a lens Q. U.S.P. 1,738,095 is referred to.

Both P. D. Brewster (E.P. 130,002) and A. Hamburger (E.P. 237,441) patented means for adjustment of a diagonally divided prism cube to obtain identical images on both planes. In the former patent 518

the positions of the registration pins, or of the gates themselves, could be adjusted. The prism could be turned about a vertical axis to adjust one image laterally, and it could also be tilted. Hamburger mounted

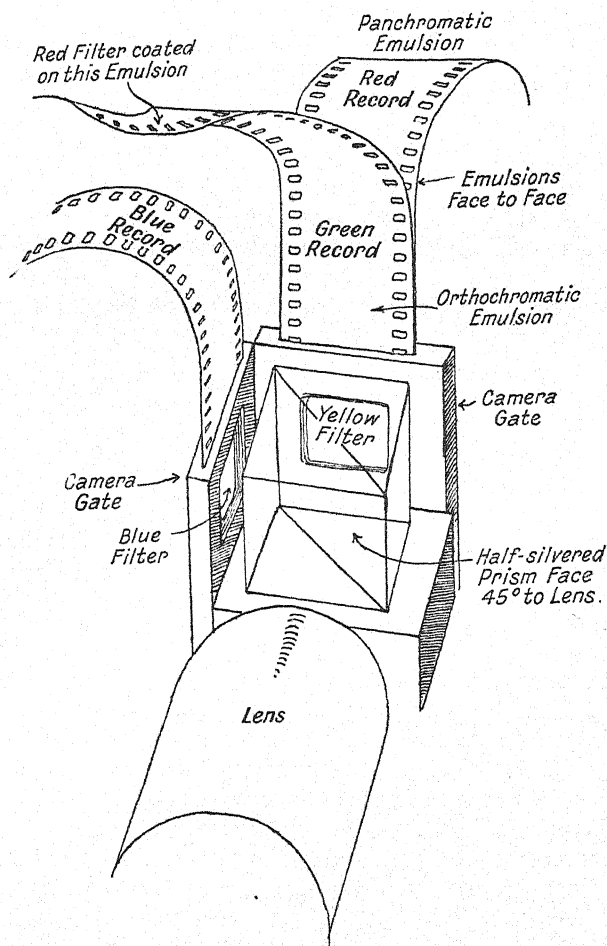


FIG. 262.—Beam-splitting system as used by A. Hamburger for three-colour negatives. Patented also by Technicolor. Compare filter arrangements.

his prism in a metal carrier, having bearing surfaces formed as parts of a sphere; in fact, a species of universal joint (Fig. 262).

Brewster patented a perforated metal reflector situated at 45° to the beam (E.P. 100,082). Such reflectors are apt to give diffraction fringes and other minor optical errors.

The patent history abounds in ingenious prism systems which have

been proven impracticable, or which have fundamental defects overlooked by their inventors.

Any design coming under this category must meet the following conditions:

1. The aperture of the prism system must accommodate the whole angular field of the objective (perhaps 40°).
2. The focus of the objective must be at least as short as 35 mm. if required.¹
3. Perforated reflectors and ruled silvering should be suspect.
4. The beam paths through glass must be identical.
5. Each part-reflection should take in the whole cone. Any system dividing the beams by reflecting *part* of the cone of rays is certain to be defective.
6. Preferably the part-reflecting surface should be evenly metallized (by cathode discharge, for instance).

To avoid the diffraction given by parallel silver rulings, D. F. Comstock and Technicolor suggested (E.P. 127,308) silvering in odd island patches turned in all directions. The writer has no information as to the efficacy of this type of reflector.

Warner Brothers have patented a very original three-colour beam-splitter 35-mm. camera (Fig. 263) in which the three records are carried by two films only. The two film pull-down actions are arranged to move the film forward two frames at a time, thus exposing alternate frames. One of the two films, having been used as the rear element of the bipack, is introduced in a second gate such that the unexposed frames are now exposed. This method necessarily results in only half of the front film being exposed, and a skipping printer must be used subsequently. Negatives taken with this camera could obviously be used for making Technicolor matrices; alternatively, it is suggested by the inventors that the negatives could be used to make prints on a positive material of the integral layer type (namely, Agfacolor positive) by successive or simultaneous printing. This would, no doubt, work very well. The writer has no information as to whether the camera has in fact been constructed. The optical system is of the conventional type and in principle is identical to the Technicolor prism. The respective positions, however, of the bipack and single film are radically different, since the single film is exposed on a horizontal plane *beneath* the prism, the 45° reflecting face of which directs the image downwards at 90° to the optical axis of the lens (Fig. 264). The camera as illustrated in the patents would be a very bulky instrument, apparently exceeding even the size of the Technicolor instrument. (U.S. Patents 2,353,797; 2,366,578; 2,374,014; 2,374,015.)

¹ Both the Technicolor and Dufaychrome cameras can use 25 mm. focus lenses of special design.

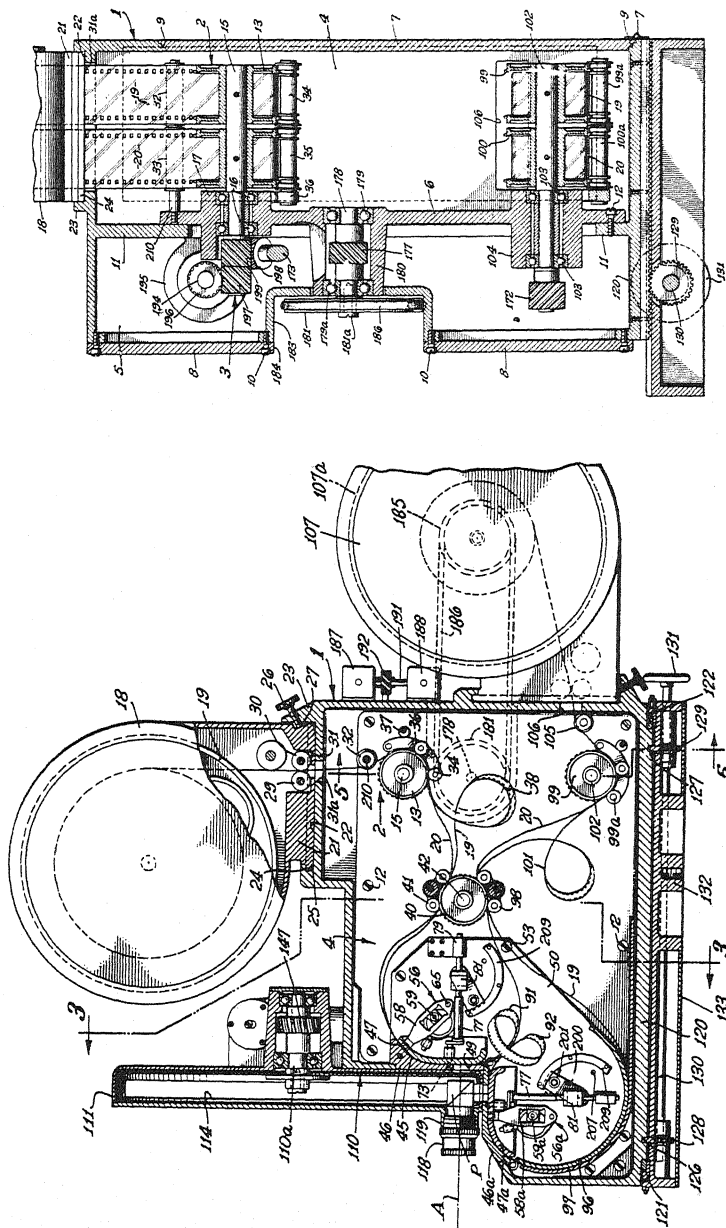


FIG. 263A.—Warner Brothers' Beam-Splitter Camera for "Three-strip" film.

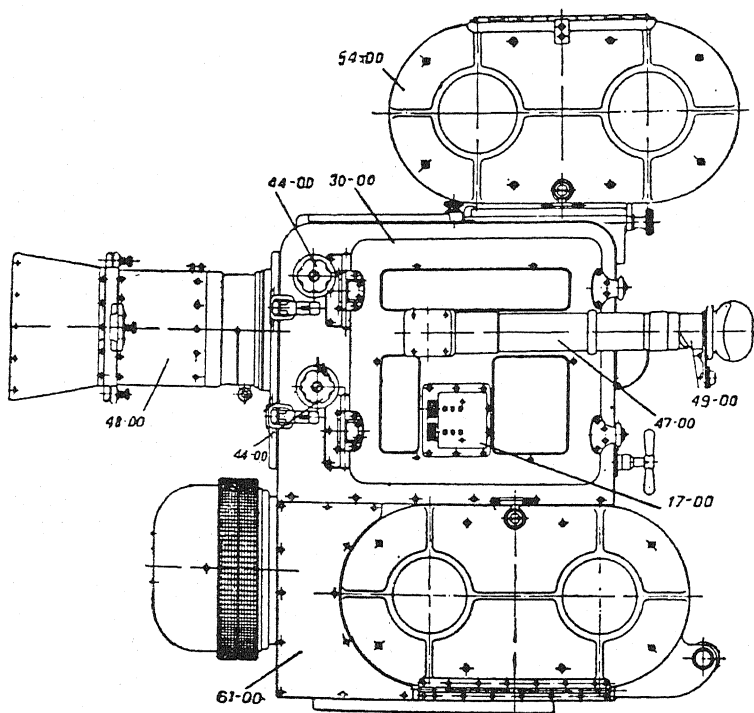


FIG. 265.—The Russian ZKS-1 Colour Camera.

COLOUR-CAMERAS AND BEAM-SPLITTING SYSTEMS

The Russians built a three-colour beam-splitter in 1936 known as ZKS-1 (Fig. 265). This was designed and constructed in Leningrad

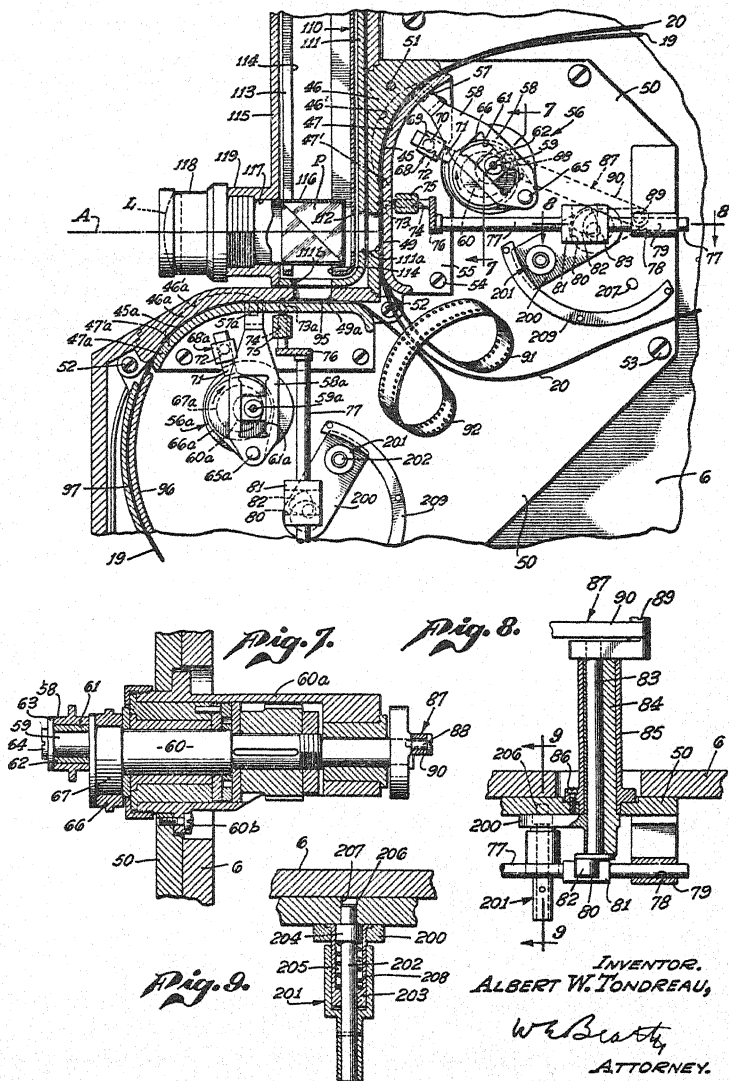


FIG. 263.—Warner Brothers' Beam-splitter camera for "Three-strip" film.

under the supervision of A. A. Minn (9). Once again the optical system is conventional and follows Technicolor in prism type. As usual, bipack is exposed in one gate and single film in the other. The position

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of the magazines is very odd. The film for the single-film gate is fed from and returns to a magazine in the normal position above the camera body, but the bipack films are fed from a magazine attached to the base of the camera. It is said that a 75-mm. $f/1.8$ objective is generally employed, but a 50-mm. can be used if required. The camera casing is self-blinded. It seems that negatives made with this camera were

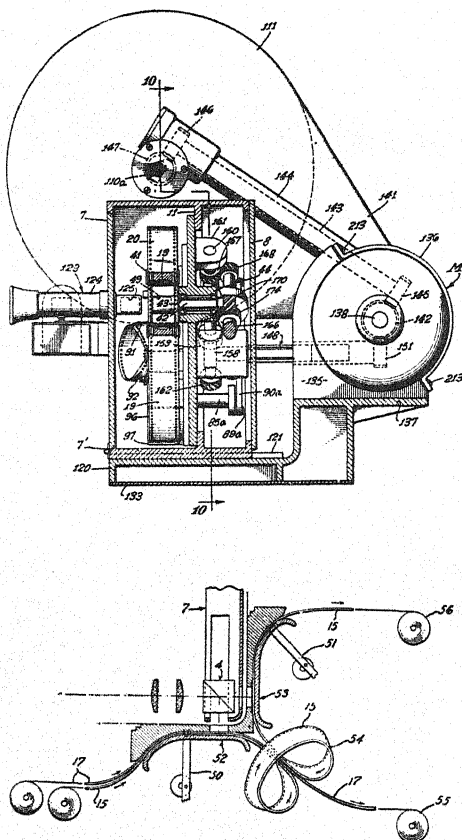


FIG. 264.—U.S.P. 2,374,014 of Warner Brothers (B. C. Haskin).

used for printing by a method entailing successive coating and printing of bichromated gelatine layers. These layers were exposed and dyed by methods analogous to Pinatype (namely, without forming a wash-off relief). Printing required high-pressure mercury vapour lamps in order to obtain adequate U.V. intensity, and a speed of 750 ft. per hour was attained.

The optical system of the Dufaychrome (originally British Tricolour)

camera (see page 526) belongs to this category. This camera, designed by Mr. Jack H. Coote and Mr. Gilbert Murray, is of the "bipack and one" type—exposing a bipack of two films at one exposure aperture and a third, single film, at a second exposure plane. A prism block divided at 45° and metalized with gold provides the two required light paths. Blue and red record negatives are obtained by reflected light as front and rear elements of the bipack respectively, while the green record is exposed on the single film by transmitted light. Two Vinten Model "H" film movements of the latest type are incorporated in the camera.

Employment of two standard movements effects obvious economies, but involves certain problems of design.

In order to avoid threading difficulties it was decided to make the whole of No. 2 mechanism, operating the film recording the reflected beam, a movable assembly, swinging into and out of its operating position as required. It was considered necessary to be absolutely certain that the design and construction of such a "swinging gate" would prove satisfactory under all working conditions.

Various measurements, therefore, were made on the camera in order to test the consistency of register of the relevant moving parts of the camera mechanism, and also to check for variation of register between the two film gates at various temperatures.

The swinging gate was repeatedly opened and closed, measurements of position being made at each closure after clamping tightly with the clamp. A suitable target was mounted on the gate and viewed with a microscope mounted on the fixed frame of the camera. Movement in a vertical or horizontal direction did not exceed 0.0001 inch.

Measurement of angular position was made with an autocollimator and reflector. An angular variation of $\frac{1}{2}$ minute about a vertical axis was obtained, because of slight variations in the clamping pressure. This amount represents about 0.00015 inch over the width of the film gate.

The method of locating the prism block with a dovetail slide and end stop, gave location both for angle and position, with variations of not more than 0.0002 inch.

A crossed line target graticule was mounted in each film gate so that the images were approximately superimposed when viewed through the prism system with a long-focus microscope.

The whole camera was placed in a refrigerator and allowed to settle to a steady temperature of approximately zero degrees centigrade. The camera was then removed and the microscope was set up to view the targets through the prism; measurements were then made of the relative position of the targets both horizontally and vertically.

The temperature was gradually raised to approximately 100° F. (38° C.), microscope observations being taken at intervals. Some

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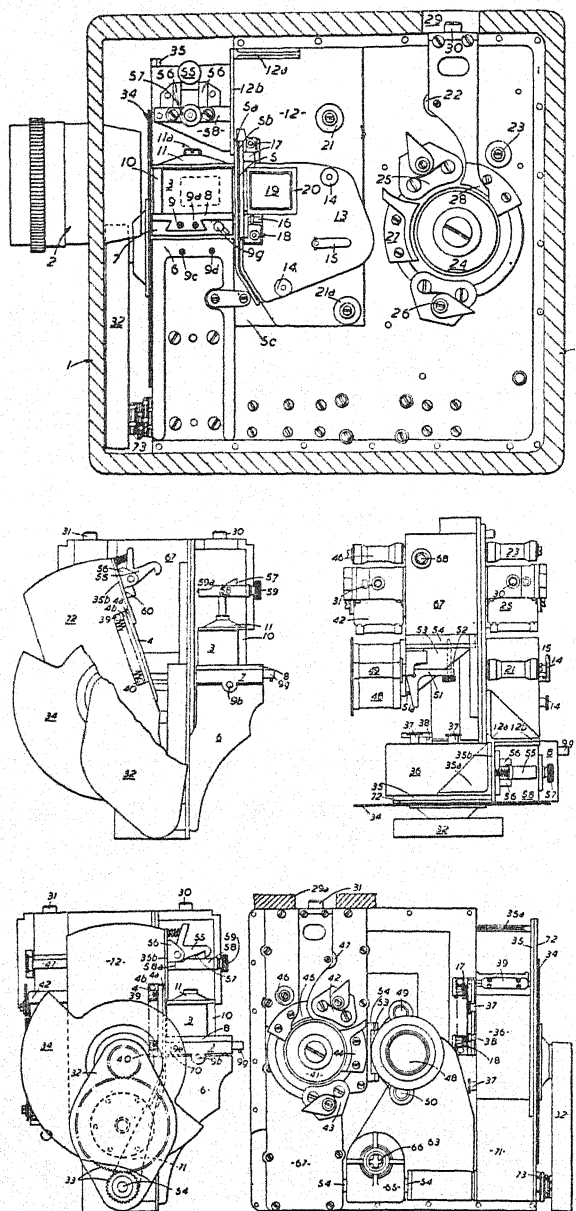


FIG. 266.—Dufaychrome three-colour camera.

difficulty was experienced at the lower temperatures because of condensation on the glass surfaces, but variations measured in either direction did not exceed 0.0005 inch.

The way in which the No. 2 assembly can be swung away from and returned to its operating position should become apparent after reference to Fig. 266. The main drive shaft runs along the base of the camera, doing No. 1 movement through a combination of helical and spur gears and No. 2 movement via a train of three gears located ahead of both the mechanism and the shutter. The outer surfaces of the forward bearings of the main shaft provide the journals on which the whole of the movable assembly is pivoted.

It will now be realized that although the closed or exposing position of the movable gate has been referred to as its operating position, the mechanism can, in fact, be rotated while in its open or loading position, a feature which is essential for efficient threading.

The bearings at the base of the movable assembly operate in conjunction with a tongue at the top of the gate which enters a slot for lateral location and butts against an anvil set at right angles to the direction of swing. The assembly is locked into its closed position by means of a spring catch and single thumb-screw.

Accurate placement of the two film-moving mechanisms of a colour camera represents only a part of the problem of ensuring precise registration between the images formed at the two gates. Since it is essential in practice for the prism block to be removed easily for cleaning, means must be provided for replacing it quickly with at least as high a degree of accuracy as that set for any other associated movable component.

The most convenient method of checking the position of the prism block in relation to the two exposure apertures is to illuminate two identical target images while located in the gates by the register pins, and to view them from the lens position by means of a simple microscope. The target images may be made photographically upon normal film stock, or may consist of a pattern of holes drilled coincidentally through two strips of thin metal carrying accurate negative perforations.

Except when the prism block is perfectly adjusted, the two targets will not appear coincident when viewed through the microscope, and it seemed desirable that any adjustment of the prism block should be observed continuously through the microscope without the necessity of removing the block from the camera in order to effect adjustment in any of the desired directions.

The adjustable mount which was adopted is shown in Fig. 267. There are three directions of movement provided (Fig. 267A), two rectilinear and one pivotal. All these movements are controlled by micrometer screws and locked with setscrews.

The three prism-block movements, together with the prior location of

the two exposure planes in a precisely vertical position at right angles to each other with registration pins in a common horizontal plane, provide the means of obtaining perfect registration.

It has already been mentioned that the reflecting surface of the prism block is metallized with gold in order to take advantage of the well-known dichroic effect which is peculiar to thin films of that metal. With the gold surface a single high-speed orthochromatic emulsion is exposed behind a yellow filter in the transmitted beam, while a bipack with a high-speed non-colour-sensitized element in front and a highly red-sensitive element in the rear provides the blue and red records, respectively. The emulsion of the front element of the bipack carries a red-filter layer.

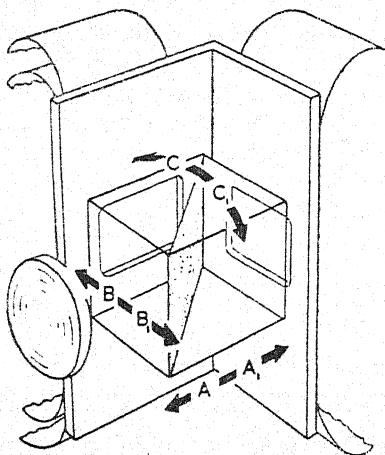


FIG. 267A.—Three directions of prism adjustment.

An unavoidable result of inserting any light-dividing means, except rotating reflectors, between the camera lens and the film planes is a serious increase in the minimum separation which it is possible to have between the rear element of the lens and the film planes. As this minimum distance is usually about 50 mm., even the advantage to be gained from the use of a glass with a high index of refraction for the prism block does not reduce the effective distance sufficiently to permit the use of normal 25 or 35 mm. lenses.

This difficulty had been met by the use of lenses of the negative-telephoto type, which have an effective focus considerably less than their back focus. Unfortunately this solution of the problem gives rise to distortion and cannot, therefore, be considered satisfactory. With this in mind, C. G. Wynne, of Wray Ltd., succeeded in computing a 35 mm. objective without recourse to a supplementary lens, although a negative supplementary still has to be tolerated for a lens of 25 mm. effective focus.

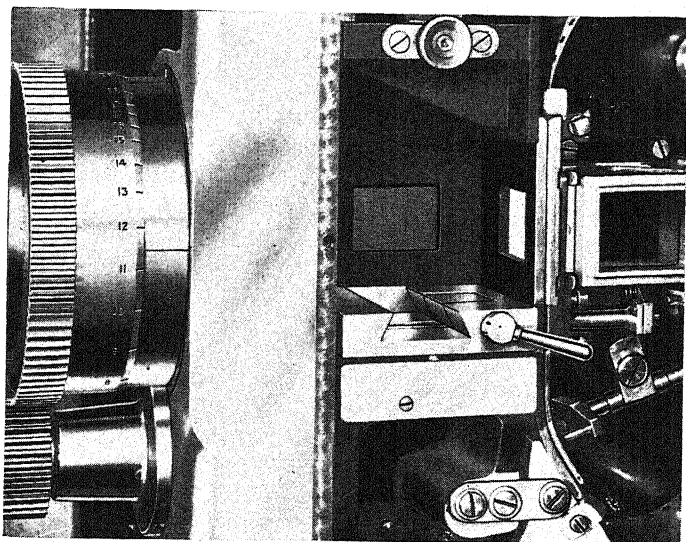


FIG. 267.—Dovetail slide for prism mount. Dufaychrome camera.

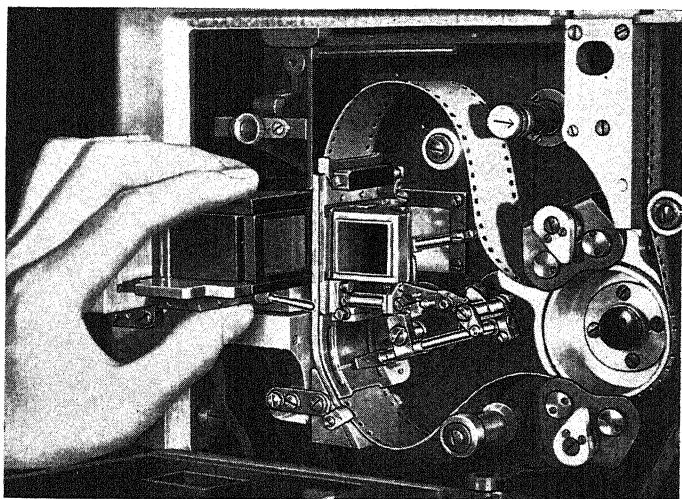


FIG. 268.—Single-film mechanism and prism block.
Dufaychrome camera.

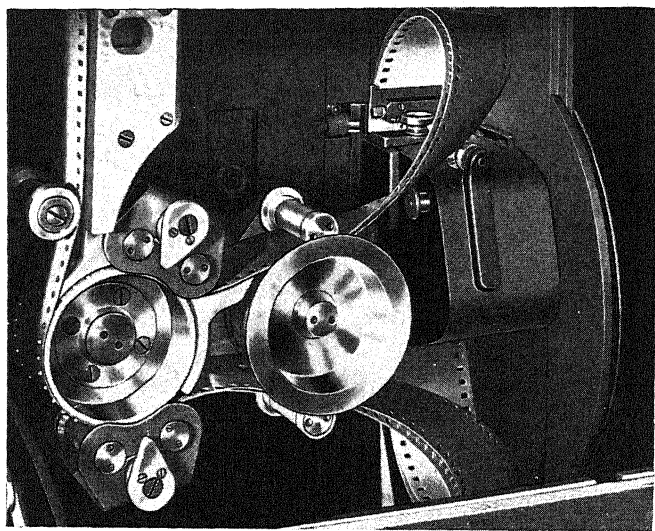


FIG. 269.—Bipack side showing removable guide roller.
Dufaychrome camera.

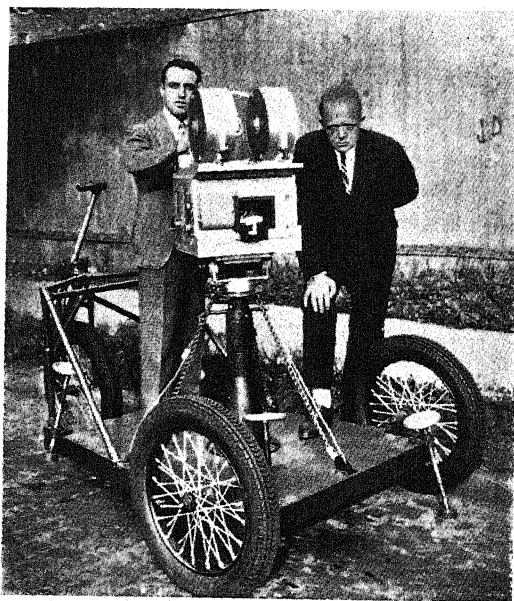


FIG. 274.—The late P. D. Brewster (right) and D. D.
Cavelli (left) with the Brewster three-colour camera.

However, it cannot be suggested that the performance of the objective is the only factor influencing definition in any camera using bipack, for the inferior resolution which results on the rear element of any bipack sets a most serious limitation upon the definition of the final composite print. Loss of definition from this cause cannot be avoided, but it can be reduced to a minimum in two ways: by the use of the most suitable emulsion (coated at an optimum coating weight) for the front element of the bipack, and the maintenance of the most perfect contact obtainable between the two films of the pack consistent with freedom from excessive drag or scratching during exposure.

A solid metal pressure pad, very lightly sprung, having a pyramidal crown of 0.002 inch is employed. This pad is so effective in ensuring perfect contact between the two films that a resolving power of 30 lines per mm. is obtained on the rear element at the same time as the front element resolves 56 lines per mm.

Focus adjustment may be made at the camera by means of a control knob, or remotely by means of Magslip motors, the latter method always being used when the camera is in its blimp. For focusing directly on to the single green record film, a magnifying "look-through" system is provided, and the image is observed through the glass pressure pad (Fig. 268).

Parallax compensation is effected automatically by the operation of focusing the camera lens. A Mitchell erect-image self-focusing finder is used, but it has been found possible to reverse the optical head and thereby reduce the separation between camera and finder lenses to about 4 inches.

The means by which parallax is automatically corrected for all lenses is thought to be novel and should merit detailed description. Each lens mount carries its own permanently attached annular cam, which upon insertion of the lens into the camera, engages with one of two rollers attached to a pivoted arm (Fig. 232). A flat bearing surface attached to the inside forward end of the finder is urged by spring pressure into contact with the second roller on the pivoted arm. Upon rotation of the lens sleeve during focusing, its accompanying cam serves to alter the position of the pivoted arm and with it the angular relationship between the finder and the camera.

The Magslip motors required for the dual purpose of focusing the lens and adjusting the view finder are somewhat larger than would be necessary for focusing only, but it is considered that the inconvenience of the additional weight is more than offset by the advantage of having combined focusing and parallax compensation under all operating conditions.

While a single magazine could have been made to house the three films, it was decided that certain advantages could be obtained by using one bipack and one single-film magazine. The chief advantage of this

arrangement is that with one magazine loading from each side of the camera, it becomes possible to reload while the camera remains in its blimp. Furthermore, the problem of minimizing film flap, particularly serious when three films must be transported simultaneously, is to some extent simplified when the two films comprising the bipack run through the camera in combination, although fed from separate 1,000-foot rolls and wound up side by side in the same magazine.

In order to restrict undesirable movement of the bipack loops, while still permitting the two films to turn through a right angle and so enter and leave their exposing position without undue tendency to twist, a removable trapping roller is used, and this is rotated by the progress of the films themselves (Fig. 269).

This reduction of film flap and the extremely quiet Vinten movements combine to produce a colour camera with reasonably low noise level, although it is still necessary to employ a blimp which is large when judged by black-and-white standards.

The image formed by the Mitchell finder, which remains attached to the camera when the latter is in the blimp, is conducted through the wall of the blimp by means of a simple series of mirrors.

1B. PRISM BLOCK. *For three gates and three separate films.*

The prism patented by the writer in E.P. 475,415 has been successfully made, and photographic tests in a still camera have demonstrated its practicability (Fig. 270). No motion picture camera has been constructed to accommodate the prism, nor is it likely to be. The test negative showed perfect freedom from registration error and the balance of exposure all that could be desired. A colour filter is provided within the block behind each of the half-silvered surfaces so that any stray light reflected from a portion of the prism lying beyond the reflecting plane responsible for the formation of a lateral image will, when finally emerging from the face of the prism adjacent to the plane in which the said image is to be recorded, be minus light which the recording filter is capable of transmitting, or, if an emulsion is used which does not require such a filter, which the emulsion is capable of recording. As shown in the accompanying figure, the block is built up from right-angled isosceles prisms 1, 2, 3, 4. The surfaces 17 and 20 are coated with a partially reflecting surface of aluminium. Magenta (minus-green) filters 21, 22 are interposed and the prisms cemented in pairs with hard Canada Balsam and dried off. The hypotenuse faces 18, 19 and 10, 13 are polished and the surface 17, 18 aluminized and cemented to the surfaces 10, 13, with soft Canada Balsam with the interposition of a yellow (minus-blue) filter, and dried off. The filters are dyed films of cellulose acetate. This may be applied in the form of a liquid containing the dye. Of the light entering the prism, only red rays are transmitted undeviated. Blue and red will be

reflected through the blue filter 30 to form the blue component image. Alternatively, a blue-sensitive emulsion may be used without a filter. Green and red rays (yellow) are reflected through the green filter 31

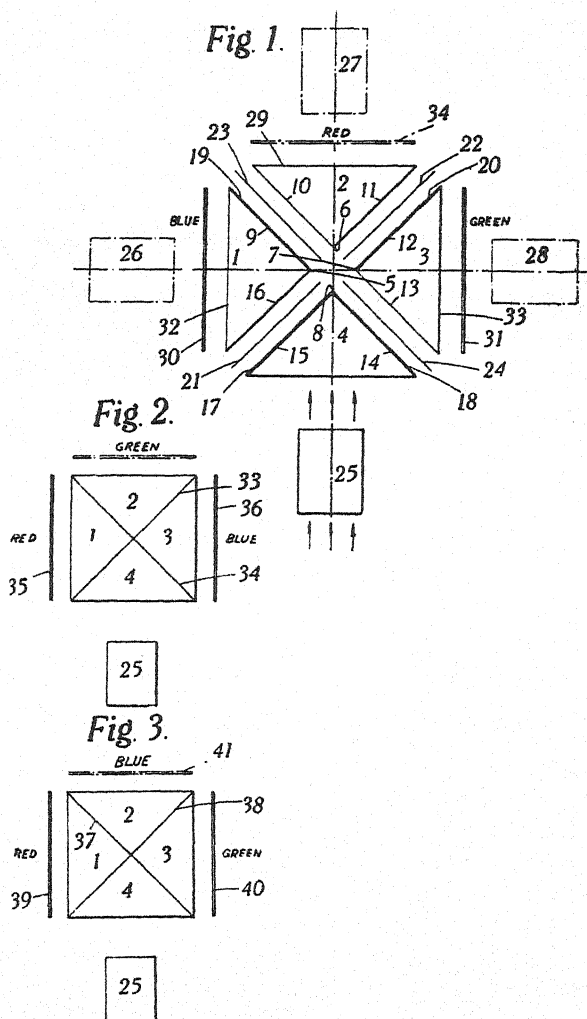


FIG. 270.—E.P. 475,415. Prism to give three images on three planes at right angles to each other (Cornwell-Clyne).

to give the green component record. (Only green light reaches the film.) Alternatively, a yellow (minus-blue) filter may be employed with a green-sensitive emulsion. The red filter 34 is optional. A single objective 25 is used. By choosing different filters for inclusion in

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the block, the planes in which the three-colour component images are recorded may be interchanged.

E.P. 472,468 of Klaver describes a somewhat similar prism, but the reflecting surfaces 6 and 9 are provided with strips (presumably fully silvered) and the surfaces of the strips which are turned away from the objective are rendered non-reflecting, *e.g.* by blackening,

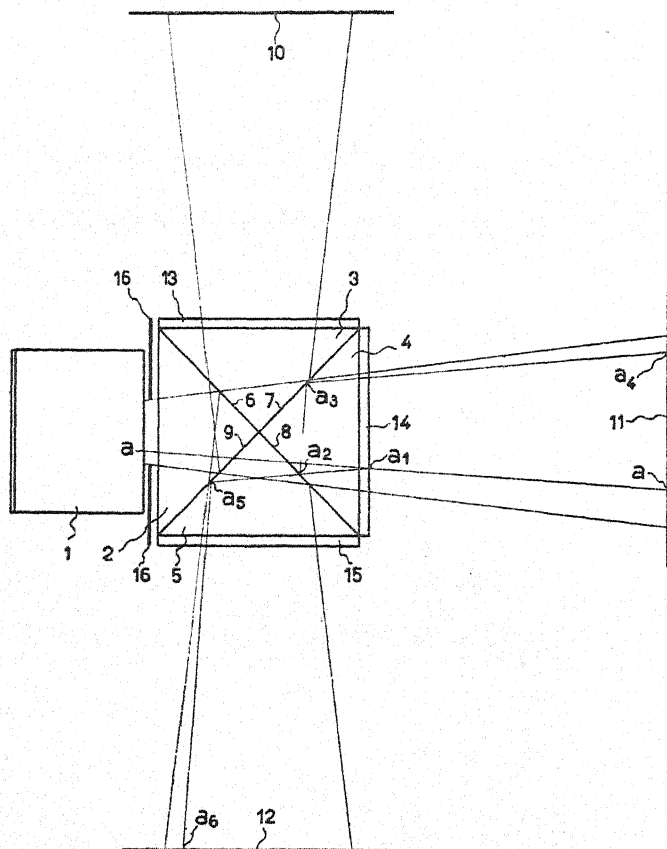


FIG. 271.—E.P. 472,468. Klaver.

in order to obviate the formation of secondary images by repeated internal reflections. The colour filters 13, 14, 15 are cemented to the exit faces of the cube. The rays incident on the cube are limited by a diaphragm 16 (Fig. 271).

Reflector systems such as that used in the Hillman still camera possess parallax errors of too serious a nature to be permitted (E.P. 357,660). In this beam-splitter several metal reflectors are of discing form and disposed one *within* the other at different angles. The

reflectors are slightly elliptical in shape. This system must not be confused with the cinematograph beam-splitter, also the invention of A. G. Hillman, which belongs to Class 3F. Hillman's E.P. 357,660 is extraordinarily similar to M. Astafiev's E.P. 251,027 and 322,767 and C. H. Nolte's E.P. 199,044, 1922.

For the student other patents of note are:

Workman, H.	}	E.P. 13,042	1915
Twyman, F.						
Higham, J. S.						
"	}	E.P. 7,659	1915
Westcott, W. B.						
Bernardi, A.						
Burger, P. L.	}	E.P. 295,643	1927
Auto Natural Films Ltd.						
"	}	E.P. 295,662	1927
Chapman, W.						
Groc, E. L., and Bernardi, A.						
Armstrong, J. J. V.	}	E.P. 316,141	1929
Cornwell-Clyne, A.						
Reckmeir, E.						
Truecolor Films Ltd.	}	E.P. 414,257	1932
	}	E.P. 407,297	1932

1C. ROTATING MIRRORS. *For reflection to two or more gates.*

The earliest suggestion of a camera based upon this principle is probably that of T. R. Dallmeyer (E.P. 22,616, 1898), in which a mirror was placed at 45° to the optical axis behind the objective lens. The mirror could be rotated, reflecting the beam in turn to the other two sides of the camera. In a still camera made in 1902, by L. Gaumont and Co. [6] (see Fig. 272), the mirror situated behind the objective was carried on an axis parallel to the three films. In one position the mirror reflected the image to the film R and simultaneously exposed G. At the end of this exposure the mirror was moved to position M' and reflected the image to the third plate B, and the opaque screen E then prevented light from reaching G. This scheme has the germ of a possible motion picture camera in it.

In E.P. 141,368, 1919, of J. Dourlen and M. Chretien, who describe a one-lens camera in which rotating mirrors are used for successively exposing three films placed on the three sides of a rectangle, the lens occupying the fourth, the patent expressly relates to cinematography.

In F.P. 464,637 of 1913, Gebay used a single lens and three films on three sides of a rectangle, the lens occupying the fourth side. Two rotating mirrors at right angles to one another, and at an angle of 45° to the optical axis, reflected the image in succession to the three films and allowed it to pass to the central film. This is precisely the same idea as Brewster patented later.

The last Brewster camera (see Chapter II) made use of two rotating propeller-like mirrors of polished nickel behind the objective at 45° to

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the axis of the beam and at 90° to each other. Spaces between the vanes permitted the light to pass to the film opposite the objective; the rotating mirrors successively deflected the beam to the other two gates, which are at right angles to the original beam. The arrangement was thus substantially the same as that proposed by Dourlen and Chretien.

Providing the mirrors rotate sufficiently fast there is no reason to anticipate time-parallax fringes, and work which has been accomplished

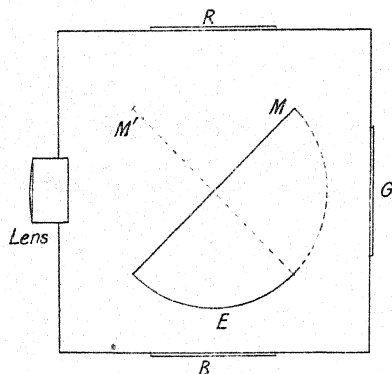


FIG. 272.—Gaumont still camera with rotating mirror (1902).

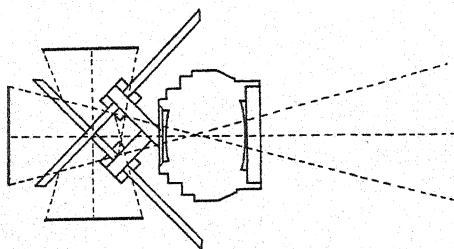


FIG. 273.—Brewster's U.S.P. 1,752,477.

with the Brewster camera has been entirely satisfactory in this respect. Brewster has unjustly been given the credit of having originated the rotating mirror method.

The principal claim in U.S.P. 1,752,477, April 1, 1930, reads:

The combination with a lens, a film-gate in the rear of the lens to support a negative film in position for exposure, a plane mirror extending between the lens and the said film-gate and occupying a plane at an angle to the axis of the lens, said mirror having at least one light-passing opening, means for revolving the mirror in its own plane, a film-gate arranged to support a negative film in position to receive light reflected by the mirror, means for feeding both films through the film-gates simultaneously step by step, a shutter for exposing both films at each period of rest thereof, and means for actuating the mirror, the shutter, and the film-feeding means in harmony with each other.

The following extract is of some interest, in which Brewster established the reason for his adoption of revolving mirrors for beam-splitting [8]:

It is generally conceded that any practical colour camera must make its colour separations simultaneously to avoid intolerable flashes or fringes of colour around moving objects and that all three separations must be made from the same viewpoint; otherwise it would be impossible to register or superimpose the several component images in the positive.

Accepting the limitations of a camera for making simultaneous separations from the same viewpoint, the next step is to inquire into the requirements of lenses with regard to focal length and speed. Under sound studio conditions where tungsten light is very largely in use and where an excessive amount of light cannot be used on account of the incident heat and strain on the actor's eyes, it is necessary to use the fastest possible lens having good colour correction. The limiting aperture at the present time is $f/2$.

The great size of the sets used in the studios, and the limited floor-space of sound stages, make it essential that the colour camera be adapted to use a wide-angle lens of not over 50 mm. focus, though 40 mm. would be still better. At the same time the beam-splitting system must permit the use of lenses of from 100 mm. to 150 mm. for several reasons. In a 50 mm. camera it is very difficult to get a double beam-splitter (adapted to reflect two images and transmit one) in the small lengths of 33 mm. or 35 mm. between the rear vertex of the lens and the focal plane; while in the case of the 150 mm. $f/2$ lens the cone of light leaving the rear vertex is nearly 75 mm. in diameter, which very greatly increases the size of the beam-splitter if no light is to be lost. Where two or three matched lenses are used it is necessary to have a beam-splitter in front of the lenses to reflect the light rays received from one point into the separate lenses; and where one lens is employed the splitter must be placed behind to divide the light rays projected from the single lens into three groups. We believe this can be done only in two ways: either by a series of glass prisms or by means of a highly polished mirror revolving at an angle to the lens and in the path of light rays. This mirror consists of a disc having a number of slots in it so that one portion of the light rays is transmitted through these slots, or openings, and after passing through a suitable filter is recorded as one of the separations; the portion of the light rays which strikes the polished surface of the blades is reflected through another filter to form the second separation; a second mirror revolving at right angles to the first is used for making the third separation. The mirror usually has three blades and makes at least two revolutions for each exposure, so that each frame is exposed two or three times. These repeated exposures have proved to give exactly the same effect upon the screen as simultaneous exposure of the different colour separations.

The glass prism system has the advantage of extending, in effect, the extremely important distance between the rear vertex of the lens and the focal plane in proportion to the index of refraction of the glass used. It also has the advantage of cheapness when compared with the revolving mirrors, while the size of the driving mechanism of the camera is reduced, thereby preventing noise and reducing the size of the camera.

The revolving mirror system has the advantage of not having to transmit the light through glass, which results in a loss of light, but, what is more important, a possible loss of definition near the edges of the picture if the glass path is too long. Most important of all, it is possible with a revolving mirror system to make three-colour separations on three separate films from a 50-mm. $f/2$ lens without adding any lenses to the standard objective to increase the light path between the rear vertex and the focal plane.

Brewster proceeds to examine the efficiency of the standard tricolour Wratten filters in relation to panchromatic film, and reaches the conclusion that by using three separate films it is possible to use an ordinary blue-sensitive emulsion for the blue separation, and remarks that the sensitiveness of this type of emulsion stops almost exactly at the ideal point, and not having to use a filter its speed is many times greater than by using a standard tricolour blue filter with a panchromatic emulsion. "Advantage can be taken of this fact by reflecting only a small portion (possibly 10 per cent. to 14 per cent.) of the light rays received from the blue separation." Similarly, for the green separation he would use an orthochromatic emulsion and a K2 filter, and gains in efficiency would again occur. The red separation will best be made with a Wratten filter No. 25 and a panchromatic emulsion. He next argues that there is a great advantage in being able to adjust the development of each film so as to compensate for the wavelength gamma effect. He examines the conditions for printing and hypothesizes as ideal a film which was later realized by multilayer three-colour positive materials. "The ideal component image would be like a color filter, pure color imbedded in the gelatin."

The requirements for a satisfactory beam-splitting system could hardly be put better than in the above paper by Brewster and Miller.

A patent granted to O. Azzoni comes under this heading. The claim seems to be that the mirrors are of such a size and shape as to be capable of intercepting at one moment during each revolution the greater part, and preferably substantially the whole, of the light from the objective, and are driven by mechanism disposed on the opposite side of the light-sensitive surfaces to the objective. As shown, light passing through the objective O strikes the sensitive layer N2 directly, and the sensitive layers N1, N3 when intercepted by the mirrors S1, S3 respectively, both of which are driven by the motor M. The mirrors are trapezoidal, the wider ends being nearer the axis of rotation (Fig. 275).

1G. *This class is represented by E.P. 556,426 of the Cosmocolor Corp., U.S.A.*

CLASS 2. Two or More Lenses without Beam-Division

This category may be dismissed as of historical interest only. Such an optical arrangement must of necessity give rise to parallax. It is singular that so many patents were granted for an optical system inherently defective (Fig. 276). To include within the normal image area two or more miniature pictures, inventors in the early stages of the art had recourse to sawn-off lenses in an attempt to get the axes of the beams as close to each other as possible and thus somewhat to reduce the parallax effect. Early patents, such as Christensen's E.P. 7,514, 1908, Pfenninger's E.P. 25,908, 1906, and M. Maurich's 534

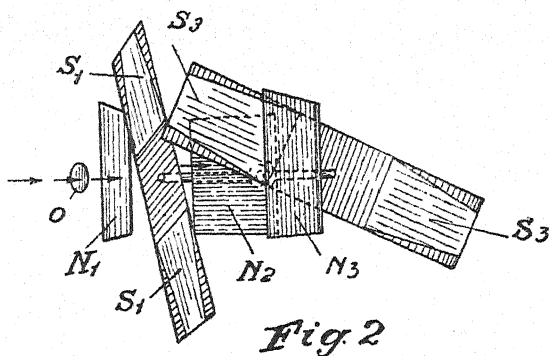
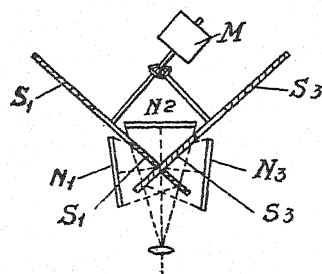
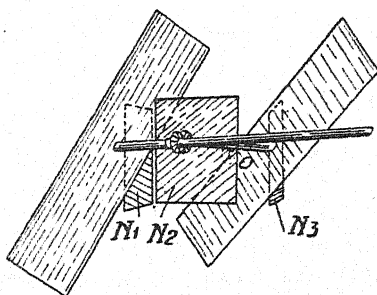
Fig. 1*Fig. 2**Fig. 3*

FIG. 275.—E.P. 459,636. O. Azzoni.

E.P. 13,150, 1912, describe such lens arrangements. The Gaumont three-colour additive films exhibited in 1912 were taken with three lenses similarly sawn off (Gaumont E.P. 3,220, 1912).¹

¹ Société Établissements Gaumont.

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R. S. Alldridge in E.P. 322,801, 1928, describes a special mount for sawn-off lenses to reduce the parallax. This type of lens mounting was used for a time by Raycol, to whom the patent was licensed, for their two-colour negatives. The distance apart of the axes of the lenses is made to vary with the focusing. Although parallax is considerably reduced, nevertheless it is still present to a degree which is not permissible in serious production.

In the Zoechrome process (E.P. 172,714, 1920) two or three small lenses are used in conjunction with one large lens of normal focus.

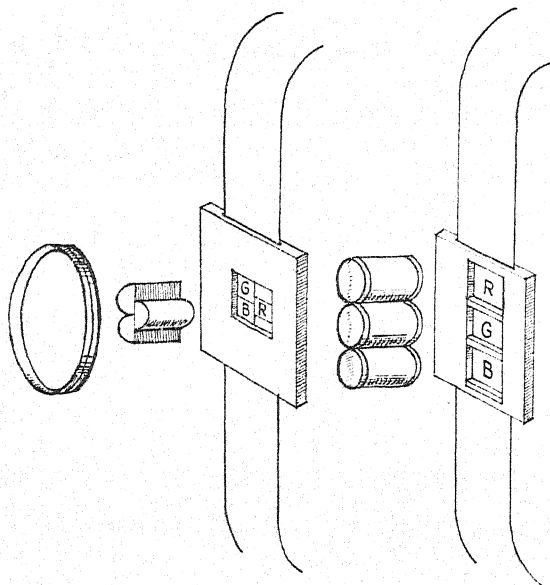


FIG. 276.—Invention and fallacy.

One normal lens is placed opposite the first frame and three small sawn-off lenses immediately below it opposite the following frame. Two or three small pictures occupying one frame alternate with one full-frame picture. No effort is made to reduce the serious parallax which occurs in such a system. Apparently, reliance is placed upon the colouring method to reduce the parallax colour fringes. The full-sized picture is printed in black-and-white, and the small pictures are enlarged and printed in superposition by an optical printer. The effect of the black-and-white "key" image is strong enough to overwhelm the faint colour fringes introduced by the three enlarged images. The colouring process involved recoating the positive film with *emulsion* for each colour.

CLASS 3. Two or More Lenses behind a Prism System for Beam-Division, or behind a Partially Reflecting Mirror or Mirrors

3B. *Disposed horizontally for two or three films, each in a separate gate but in the same plane—e.g. the films are run side by side.*

Under class 3B, Fig. 277 represents diagrammatically a prism scheme by Bellingham & Stanley Ltd. which has not been actually constructed. It is of interest as a solution of the problem of dividing the beam in such a way as to permit the gates to be placed in one horizontal plane.

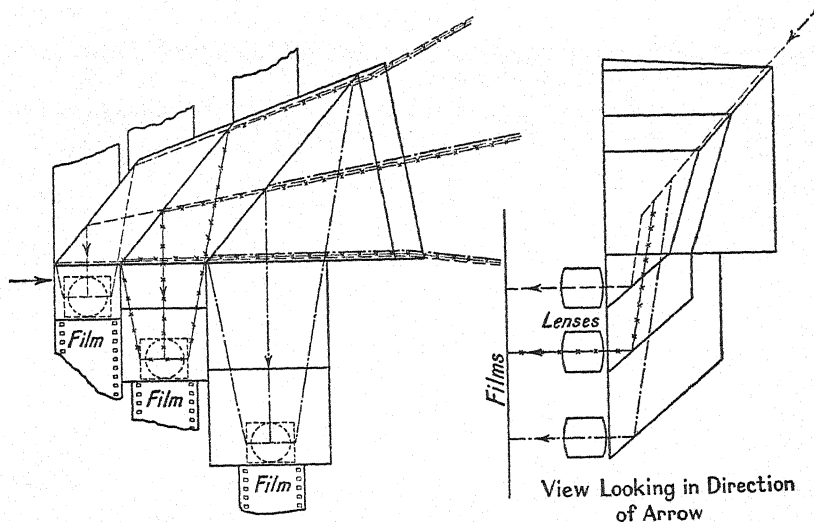


FIG. 277.

3C. *Disposed horizontally, the images being recorded on extra-width film.*

Under this class is the early Cinecolor (British) prism unit illustrated opposite page 271. (Also see Fig. 3, page 273, Historical Summary.) This was constructed for the old Cinechrome Ltd. in 1921 under the Hilger-Workman patents (E.P. 7,659, 1915; E.P. 16,810, 1915). The 70-mm. film which was used had perforations down the middle of the film, besides the usual edge perforations. The unit consisted of a huge prism block in front of two complete objectives.

3D. *Two or three pictures of substandard size in the space of one normal frame.*

The beam-divider (E.P. 398,100) developed by Bellingham and Stanley in collaboration with the writer was latterly used as an anti-parallax optical unit for the Raycol two-colour additive process. Two pictures were taken in the space of one frame, one beneath the

other. The unit was novel in that it made use of Iceland spar as a double refracting medium. The arrangement comprised a prism of the Nicol type combined with means whereby the reflected beam was again reflected at a surface parallel with the reflecting surface of the prism so as to emerge parallel to, but spaced from, the incident beam and the component transmitted by the prism. In the form shown (Fig. 278) the equivalent of a Nicol prism is formed by two glass prisms A, B, separated by a layer C of doubly refracting material. The light reflected by the layer C enters a prism D having a reflecting surface E parallel to the layer C, so that it emerges from the prism D in a direction parallel to that of the beam transmitted by the layer C and prism B. A rhomb G having two parallel reflecting surfaces may be placed against the exit surface of the prism B so as to alter the displacement between the two emergent beams without affecting their parallelism. The optical paths may be equalized by extending the

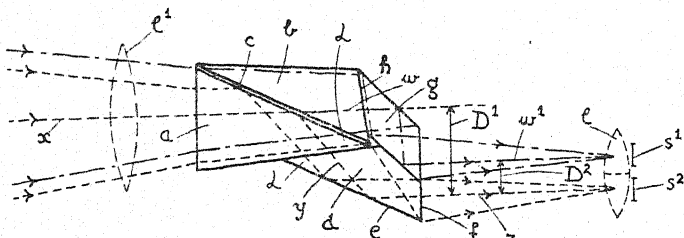


FIG. 278.—Bellingham and Stanley's E.P. 398,100.

appropriate exit member. The prism can be used either with two objectives in rear or with a single lens in front of the dividing prism.

J. M. Gutmann and P. Angenieux in E.P. 437,414 describe an optical system under this category. We quote the abridgment below (see Fig. 279).

"Apparatus for taking cinematographic pictures in natural colours comprises three objectives O1, O2, O3, Figs. 2, 3 and 4 (Fig. 279), mounted close enough together to give simultaneously three separate images R, G, B, Fig. 1, in one normal picture space A of a standard cinematograph film, three colour filters for the three colours, each associated with one of the three objectives an optical system in front, of the objectives having a semi-reflecting surface M1, Fig. 2, and a totally reflecting surface M2 located to secure two of the images R, G from a single point of view, and an oblique prism Q, Fig. 4, with parallel faces placed against the optical system to secure the third image B from a different point of view, the optical system and the oblique prism being so disposed that none of their faces or edges cuts off any part of the field of view of any of the three objectives. The optical system may consist of a prism block having the semi-reflecting surface

M1 and totally reflecting surface M2 inclined at 45° so that the incident beam I1 is divided between the two objectives O1, O2, the surface M1 being half-silvered to a suitable density or fully silvered with parts of the silvering removed; alternatively, two parallel mirrors, one semi-transparent and the other totally reflecting, may be used instead of the prism block. In a modification, in order to avoid parallax, that is, to secure the third image from the same point of view as the first two, a second optical system similar to the optical system P may be arranged obliquely in front of the above-described arrangement. In a further modification, suitable for use in poorer light, the arrangement of

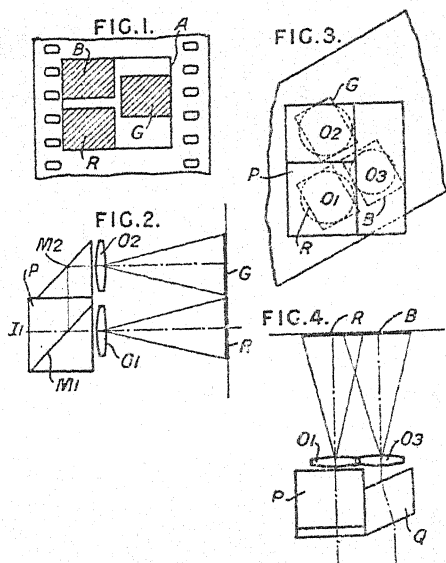


FIG. 279.—E.P. 437,414. J. M. Gutmann and P. Angenieux.

prisms P, Q is supplemented by an adjustable focusing lens placed in front to focus the feature of greatest interest at a constant distance from the objectives. A second lens may be added to form an afocal system when focusing is effected at infinity. Specifications 306,329, (Class 97 (i)), 385,141, and 419,894 are referred to." A projection system is described in E.P. 443,061. A multiple lens mount is covered by E.P. 438,982.

The extremely complex prism covered by E.P. 459,664 of Bellingham and Stanley was made for Gasparcolor Ltd., under the writer's direction (Fig. 280). The block contains two semi-reflecting and transmitting surfaces A, B to divide two component beams from each other and from the third, and three internal surfaces E, F, G, to reflect the beams in the required direction, the lengths of the light paths being equal. The

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part of the beam reflected by the partially metal-coated surface A of the six-sided component prism 1 suffers total internal reflection at the opposite surface C of this prism, and is then reflected out of the combination by the surface F of a triangular prism 5. The transmitted beam is totally reflected by the surface H of a triangular prism 2

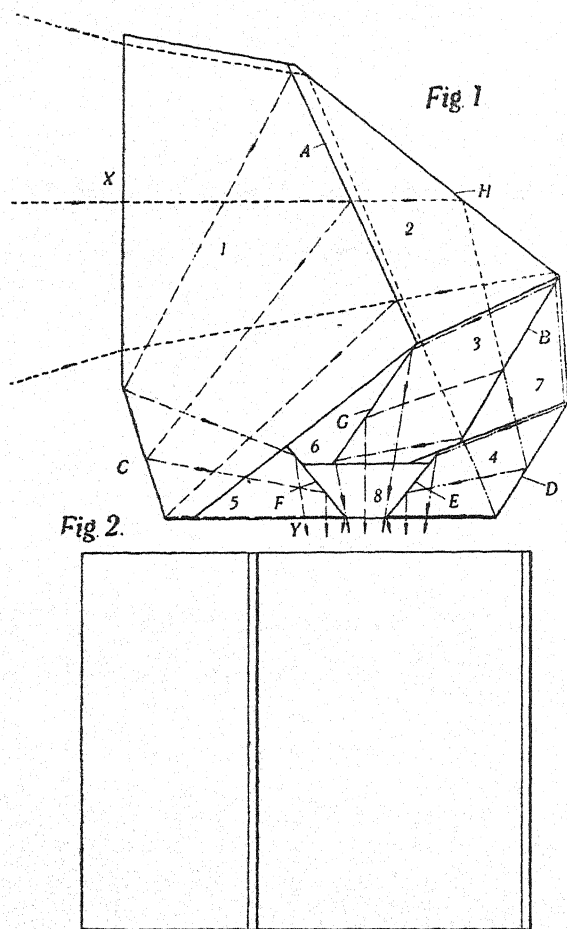


FIG. 280.—E.P. 459,664 of Bellingham and Stanley.

on to the partially metal-coated surface B of a rhomb 3, where the beam is again divided. The reflected portion is reflected out of the combination by the surface G of the rhomb 3, and the transmitted beam, after total reflection at the surface D of a rhomb 4, is reflected out of the combination by the surface E. The three beams emerge parallel to each other from the surface Y of the combination which is perpendicular to the plane of the paper.

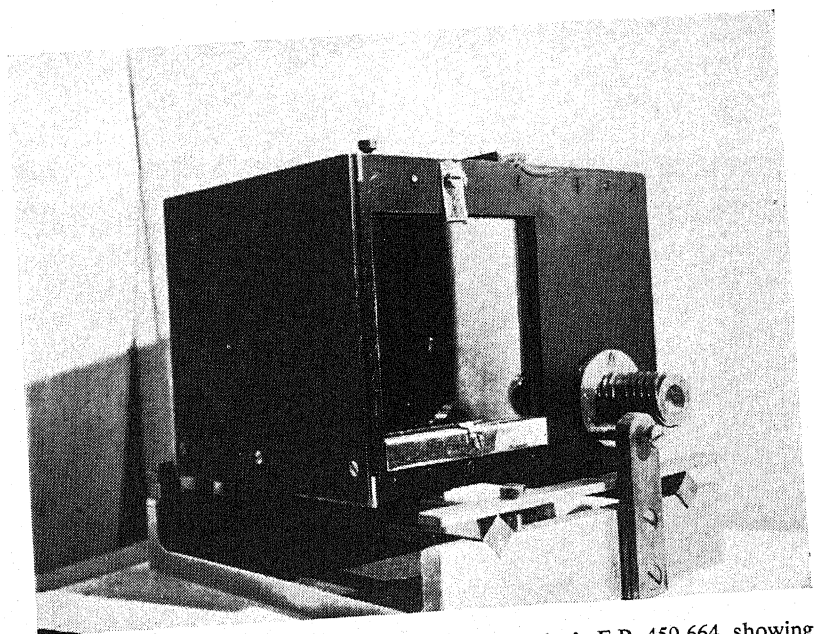
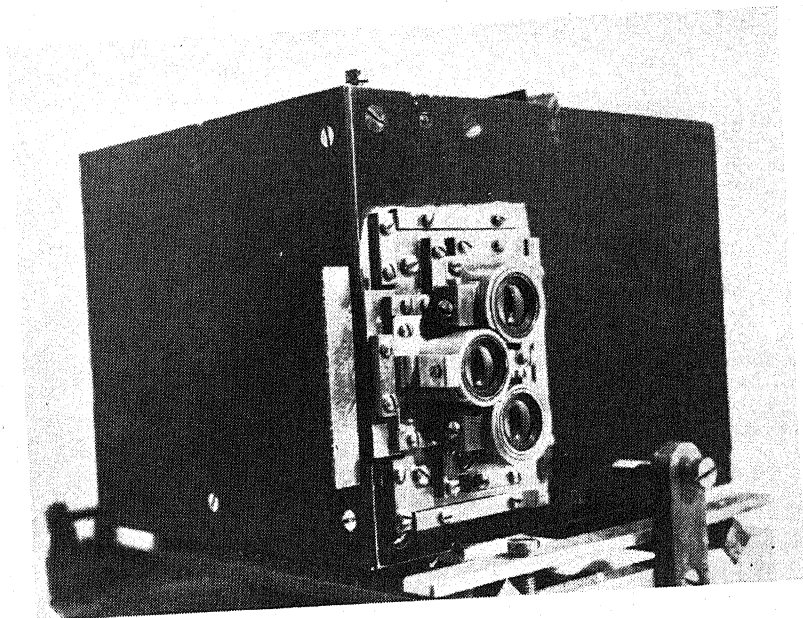


FIG. 281.—Prism according to Bellingham and Stanley's E.P. 459,664, showing mounting and lens objectives.

(Facing p. 540)

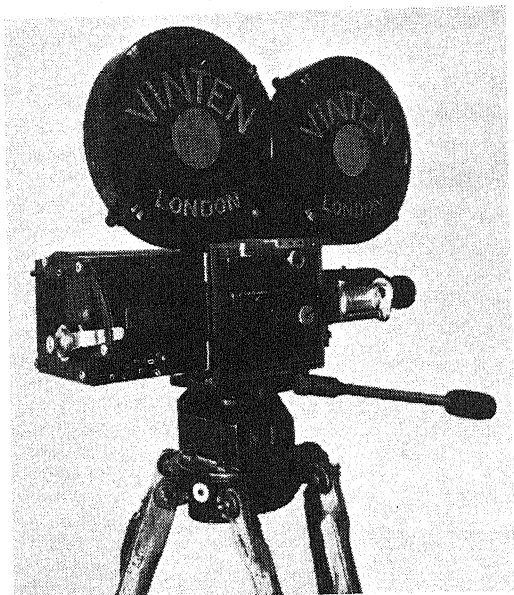


FIG. 282.—Prism according to Bellingham and Stanley's
E.P. 459,664, mounted on Vinten camera.

dicular to the entrance face X, and glass distance-pieces 6, 7, 8 ensure equal light paths.

An interesting patent of Bellingham and Stanley (E.P. 451,274) deals with the gate necessary to accommodate the three sub-standard images obtained with the prism just described. The exposure apertures are each of a height equal to half the length of film feed and of a width half the picture width of the film, two of them, a , b , being spaced apart in the longitudinal direction of the film so that the length d of the intervening space equals the film feed, and the third aperture c being located between them but displaced laterally so as to be clear of the space between them. The arrangement permits the use of larger lenses than would be possible if the apertures were juxtaposed, and the aperture c may be midway between the apertures a , b , so that the lens diameters may be a maximum (Fig. 283).

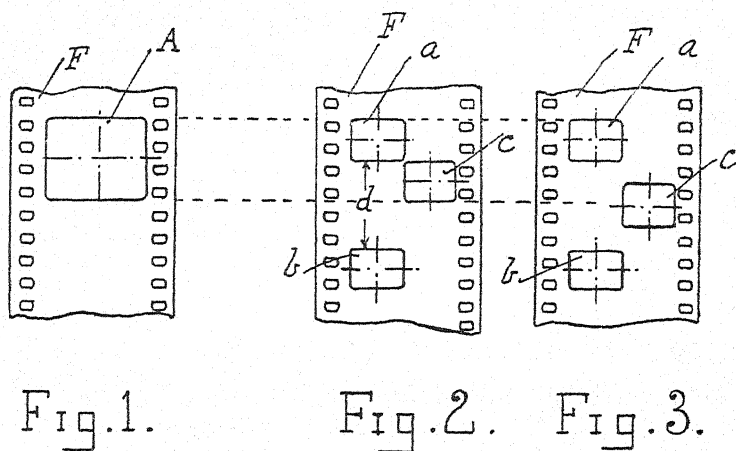


FIG. 283.—E.P. 451,274 of Bellingham and Stanley.

3E. *Two pictures in the space of one normal frame, but their axes turned lengthwise to the film.*

Under this heading an important group of patents is held by Dufay-Chromex Ltd. which were acquired in 1937 from Cinecolor Ltd., originally formed to develop the patents of D. Daponte and C. Cox. The company also owns a licence of some patents by Adam Hilger Ltd. and J. H. Dowell of that firm.

In E.P. 346,406 of D. Daponte the principal claims read as follows Fig. 284:

1. A beam-splitting prism and lens system receiving images from the same aspect for casting images side by side on the film, preferably normal-sized film with the width or horizontal lines of each picture running along or parallel to the length

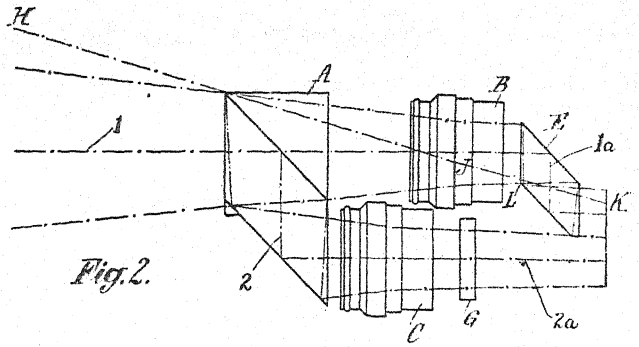


Fig. 2.

Fig. 1.

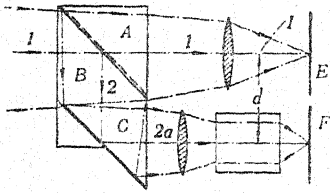


Fig. 3.

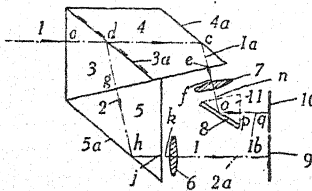


Fig. 4.

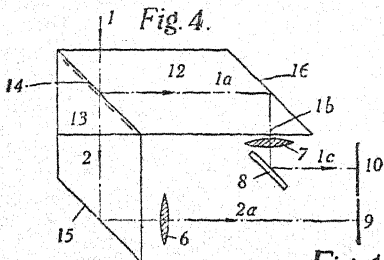
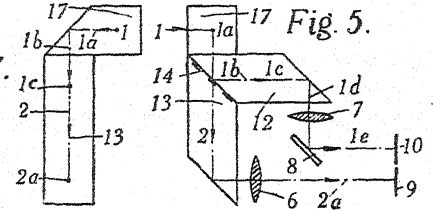


Fig. 7.



of the film comprising a light beam-dividing prism system and co-operating lenses in which the beams are separated by such an amount, and/or inclined to each other at such an angle, as will permit the use of lenses of large aperture, the separation of the beams being finally reduced and one or each of the beams redirected by a single reflecting surface between one or each lens and the film at such an angle as will form the images side by side on the film at the required separation and permit the use of lenses of short focal length.

2. A beam-dividing and taking prism and lens system as in Claim 1, constructed so as itself before the lens system to turn the images so that they appear in the required orientation on the film and permit the camera to be used in the upright position.

3. A beam-dividing taking system according to Claim 1 or 2, wherein the images are cast the same way up on the film.

4. A beam-dividing taking system according to any of the preceding claims wherein the lengths of the paths of the main and branch beams through the prisms to the lenses and the refractive indices of the prisms are so proportioned that the lengths of the paths of the two beams from the point where the main beam is divided to the lenses are optically equal.

5. A taking system according to Claims 1 to 4 in which a mirror is used between the lens and the film and the correction of the optical lengths of the paths of the beams is effected before the lens.

This was followed by E.P. 349,107 of Adam Hilger Ltd. and J. H. Dowell. The patent begins with a very important statement which should be carefully studied by designers of beam-dividing systems:

This invention relates to cameras for colour photography in which a prism or combination of prisms is used to form a number of images of equal size, each image being formed after transmission through a coloured filter. Such prisms are usually constructed of glass of the same refractive index throughout, and it is found that the images so formed, although of equal size for objects at infinity, are not of equal size for near objects. This invention has for its object means whereby such prisms can be constructed so that the images are all of the same size for objects at all distances.

The specification gives details of the necessary corrections for two- and three-colour systems:

Considering the case of a two-colour camera, it is highly important that the optical distance from the object to the lens should be exactly equal for both colours, and this is secured by proper adjustment of the two glass paths such that

$$\frac{L_1}{N_R} = \frac{L_2}{N_G}$$

where L_1 is the focal length of glass for one colour and N_R its refractive index for that colour and L_2 and N_G the corresponding length and refractive index for the other colour. Such a system is correct on the axis for objects at all distances, but this is not the case for oblique rays. With more than two colours the same conditions hold for all the colours.

The conditions necessary for complete correction of magnification at all distances for a two or more colour camera are:

(1) $\frac{L}{N}$ for each colour is equal.

(2) $(L \tan r)$ for each colour is equal where L is the length of glass path.

N is the refractive index.

r is the angle of refraction.

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Equation 1 expresses the equality of the optical reduced length for all rays on the optical axis and equation 2 expresses the equality of the total lateral shift for oblique rays.

The conditions for exact correction are stated more specifically below in the case of a two-colour camera, Fig. 3 serving to illustrate the principle (see Fig. 285). This figure represents the glass path shown as L in Fig. 2 (Fig. 285), but with a prism system according to the invention. In the figure and equations:

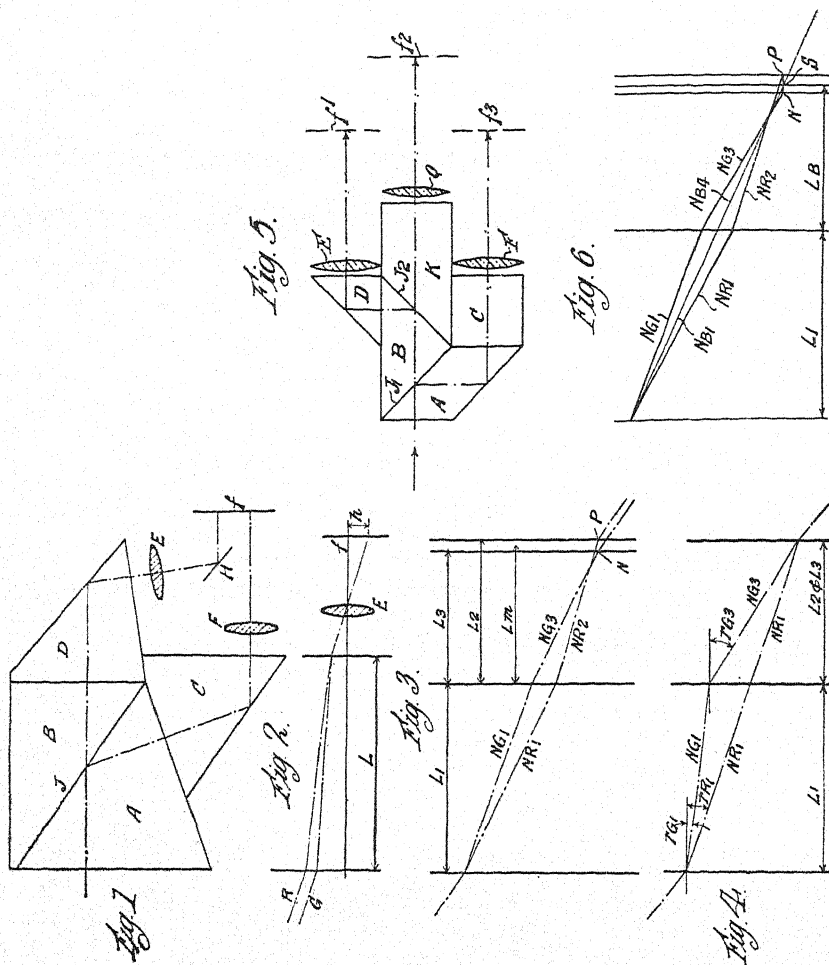


FIG. 285.—E.P. 349,107 of Adam Hilger Ltd. and J. H. Dowell.

L_1 = Length of glass common to both colours R and G.

L_2 = Length of glass exclusive to colour R.

L_3 = Length of glass exclusive to colour G.

N_{R1} = Refractive index of glass common to both colours corresponding to the mean wavelength of colour R.

N_{G1} = Refractive index of glass common to both colours corresponding to the mean wavelength of colour G.

N_{R2} = Refractive index of glass exclusive to colour R corresponding to the mean wavelength of colour R.

N_{G3} = Refractive index of glass exclusive to colour R corresponding to the mean wavelength of colour G.

r = Angle of refraction, the suffixes appended having the same meaning as those appended to N.

The condition for exact correction is then expressed by equation 1 above, which becomes

$$(3) \quad \left(\frac{L_1}{NR_1} + \frac{L_2}{NR_2} \right) = \left(\frac{L_1}{NG_1} + \frac{L_3}{NG_3} \right)$$

and equation 2, which becomes

$$L_1 \tan r_{R2} + L_2 \tan r_{R2} = L_3 \tan r_{G1} + L_3 \tan r_{G3}$$

An example of a three-colour prism system is shown in Figs. 5 and 6 (Fig. 285). Light enters the prism A and is divided at the semi-reflecting surface J1. The direct part passes through the prism B to a second semi-reflecting surface J2, which again divides this part of the light. The direct part passes through the prism K and is focused by the lens Q on the focal plane f2. The glasses A, B, and K are all of the same kind. The rays reflected at the surfaces J1 and J2 are subjected to total reflection in the prisms A and D respectively and pass through glasses C and D to be focused by lenses F and E at f3 and f1 respectively. The two indirect images on f3 and f1 are connected by glasses C and D, the mean of whose refractive indices N_{R2} and N_{G3} for their respective colours is equal to the refractive indices N_{R1} and N_{G1} for these colours in the glass A common to all colours. The method of procedure is therefore exactly the same as the first example for a two-colour camera described in connection with Fig. 3 (Fig. 285), with the addition of the direct image.

If, for example, the same particulars are assumed in this case, the mean refractive index 1.6150 would be the value for the refractive index of glass K individual to the direct image, consequently also of glass A and B for the same colour, and it would only be necessary to determine the length of glass required as follows:

According to the result obtained from formula (3), the mean reduced path length equals 2.78645, so that

$$\frac{L_1 + L_B}{N_B} = 2.78645 = \frac{L_1 + L_B}{1.6150} \therefore L_B = 4.5001$$

so that

$$L_B = 4.5001 - 2.5 = 2.0001.$$

It will be seen from Fig. 6 (Fig. 285) that, just as described in connection with Fig. 3 (Fig. 285), the points N, P, and S, where the three components of the oblique ray drawn in finally leave the glass, are at the same horizontal level, that is the total lateral shift is the same for all three components, and consequently the three images of an object at any distance are of the same size and such as will register satisfactorily in any subsequent process.

In E.P. 388,754, Adam Hilger Ltd. and J. H. Dowell patented a dividing prism combined with cylindrical and spherical lens elements to produce two or more identical images from the same viewpoint, the images having different magnifications in the horizontal and vertical directions, so that one set of companion images exactly fills one picture space on the film and the images are in close juxtaposition.

In Fig. 1 (Fig. 286) the light is received by a cylindrical positive lens 12, and then enters a prism 1 having a semi-reflecting surface 3 dividing the beam into two parts, one of which after reflection by the surface 5 passes through a negative cylindrical lens 13 and a positive spherical lens 15, while the other is reflected at the surface 7,

passes through lenses 14 and 16 to the lenses 13 and 15, and is deviated by a mirror 9, the images being formed side by side at 10 and 11. The axes of the positive and negative cylindrical lenses may be parallel or at right angles to each other, and the spherical lenses may be disposed between the cylindrical lenses instead of having the position shown. The spherical and cylindrical elements may be combined in such a way that at least one lens has a spherical face on one side and a cylindrical face on the other. The prism 1 may itself be provided with spherical or cylindrical surfaces, instead of the plane entrance or exit surfaces shown. The images are projected on to a screen 22 through a system which corrects the distortion, such system consisting for each image of a spherical lens 23 (Fig. 3) between cylindrical lenses 24, 25. The axes of the cylindrical lenses may be crossed, in which case the lenses are either

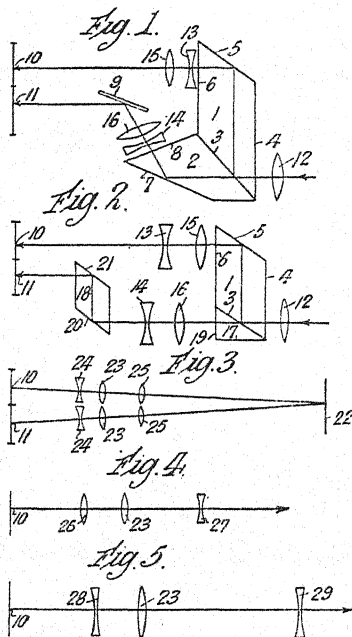


FIG. 286.—E.P. 388,754 of Adam Hilger Ltd. and J. H. Dowell.

both positive or both negative, or the axes may be parallel, in which case the lenses are preferably of opposite signs.

The most recent of the Cinecolor (British) patents is E.P. 427,983 of Adam Hilger Ltd., and J. H. Dowell of that firm. The patent is of considerable importance, as means are proposed for avoiding some of the theoretical objections to prism-dividing systems of the type in which the prism block is placed in front of two or more objectives. The complete specification will be quoted in full.¹

The invention relates to the design of prism combinations for use in cameras for colour photography of the type in which, for the purpose of avoiding parallax, the

¹ By permission of the Controller of H.M. Stationery Office.

light from the object enters a common aperture and is then divided into two or more different beams which are conducted by prisms in the light paths to a corresponding number of different photographic lenses. The conditions which govern the design of such prism combinations are discussed in the specification of patent No. 349,107, and means are there disclosed for obtaining equal magnification of the differently coloured images of objects at all distances by the use of two or more different kinds of glass in at least one beam. Cases may arise where the full correction there described is not of prime necessity, and where for reducing time or cost of manufacture a less perfect correction will be found a satisfactory compromise.

The present invention has for its object means whereby the prism combination may be constructed if desired all of one kind of glass and yet so that the different images of an object at any distance will have equal magnification within reasonable practical limits.

As shown in the above-mentioned patent specification, the lateral shift of an oblique ray of light passing through a parallel-sided plate, which is the equivalent of the prism system, depends on the refractive index, and accordingly the light arriving at any particular point on the photographic plate away from the axis comes from one point of the object in the case of one colour and from a point at a finite distance away from the first in the case of another colour. This separation subtends a negligible angle at the camera lenses in the case of very distant objects, but with near objects the effect is to produce images of different sizes which do not register satisfactorily in the subsequent processes.

In such systems the light of the variously coloured images arrives at the camera lenses by paths which are different before separation of the beams and not precisely equivalent thereafter. The lenses are usually selected to be of equal magnification in themselves. The condition for securing equal magnification of the various images is that the lateral shift relative to each lens of the oblique rays of light from the object due to the passage of the rays through the prism system should be the same for each path.

Another way of expressing this is to say that the "reduced distance for oblique rays" from the object to the lens must be equal. By "reduced distance for oblique rays" is here meant the distance measured parallel with the optical axis by which, if the prism were removed, the oblique ray would travel in air from the plane of the entrance face of the prism to the point where it cuts the optical axis. Distinction is to be made from "reduced distance" as used in customary nomenclature of geometric optics, which applies only to rays on or parallel with the axis. Assuming that the principal plane of the lens is coincident with the exit surface of the prism, the "reduced distance" is the distance at which the lens would be placed, measured from the entrance surface of the prism, if the prism were removed, that is the position which the lens would occupy with only air in front of it for equal conditions of focus and magnification.

In order to show more clearly the distinction between the reduced distance for an oblique ray and the reduced distance on the axis it may be stated that in a parallel-sided plate (which is the equivalent of a prism of the type here considered) of length L and refractive index N the reduced distance of a ray on or parallel with the axis (that is, a ray normal to the surface) is numerically equal to $\frac{L}{N}$, whereas for an oblique ray at angle of incidence i , for which the corresponding angle of refraction is r , the reduced distance for the oblique ray is $\frac{L \sec r}{N} \times \cos i$. When $i=0$, $\sec r=1$, and $\cos i=1$; we then obtain reduced distance $= \frac{L}{N}$ for a ray on or parallel with the axis.

It has been stated in the specification of Patent 349,107 that if the reduced distances of the paths traversed by light of the various colours are all made equal, such a

system is correct for objects at all distances for rays on the axis, but this is by no means the case for oblique rays.

Since, however, the error in magnification of the images on the axis is zero, and very small for small angles of oblique rays, we can disregard the reduced distance on the axis, and for a selected angle of incidence make the reduced distance for oblique rays on two or more paths equal. It will be shown later that this is accomplished when the lateral shifts of the oblique rays for the different coloured images are also equal for the chosen angle of obliquity, and it is convenient to consider first the conditions of equality for lateral shift.

According to the present invention, the lengths of path traversed by the light destined to form the images of different colours are so selected that for a ray incident at a chosen angle of obliquity the total lateral shift relative to the taking lenses is the same for all the different coloured images, irrespective of the reduced optical path length on the axis, and this may be done without necessarily using glasses of different refractive properties for the different light paths.

The angle will preferably be chosen so as to keep the errors for other angles as small as possible, due regard being paid to the relative importance of the different parts of the field of view.

The accompanying drawings serve to illustrate the principle of the invention and show two examples of dividing prisms in accordance with it, and therein (see Fig. 287):

Fig. 1 is a diagram of rectified light paths in a prism combination.

Fig. 2 is a corresponding diagram including an air space.

Fig. 3 is a diagrammatic section of a two-colour prism system, and

Fig. 4 is a diagrammatic section of a three-colour prism system.

Referring to Fig. 1 (Fig. 287) the optical axes of the prisms have been rectified to lie along the straight line A and the common entrance face is indicated by the line D, the exit faces for the colours R and G being E_R and E_G respectively. The principal plane of each lens will be assumed coincident with the exit surface of the corresponding prism or placed at an equal distance from the exit faces of the prism. A ray C enters the prism system at the height h above the optical axis and at an angle of incidence i , the angles of refraction being r_R and r_G respectively for the two colours. The path lengths in the glass are then so selected according to the invention that both rays pass out from their respective exit faces on the optical axis A, or otherwise expressed, so that

$$L_R \tan r_R = L_G \tan r_G,$$

where L_R = length of glass path traversed by light of wavelength R,
 L_G = length of glass path traversed by light of wavelength G,
 r_R = angle of refraction for light of wavelength R,
 r_G = angle of refraction for light of wavelength G.

When the glass paths are so proportioned, the reduced distances of the oblique rays are also equal for the chosen angle to the optical axis. This will be clear since the incident rays enter the prism at the same height h above the optical axis. Therefore the reduced distance of the oblique rays numerically equal to $h \tan (90^\circ - i)$ must be equal, i being the angle of incidence. Thus, since the lateral shifts of the two rays relative to the two lenses are made optically equal, and the reduced distances of the oblique rays are also optically equal, it follows that two images of identically equal size will be obtained, the lenses which form the images being placed at the same distance from the exit faces E_R and E_G respectively.

It will be understood that equality of image size is obtained only at the one chosen angle of incidence, and also on the optical axis where errors of magnification become zero, and that for smaller or greater angles of incidence the images will no longer be of equal size. Also, since the angle subtended by the image will vary with the distance of the image from the lens, that is with the conjugate focus, the selected angle for the oblique ray should be chosen for the mean position of the

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focal range, or for such position of the range of focus as is most important for the purpose in view. Where, however, the angular field is not large the departure from equal magnification is well within practical limits over the whole of the field. For

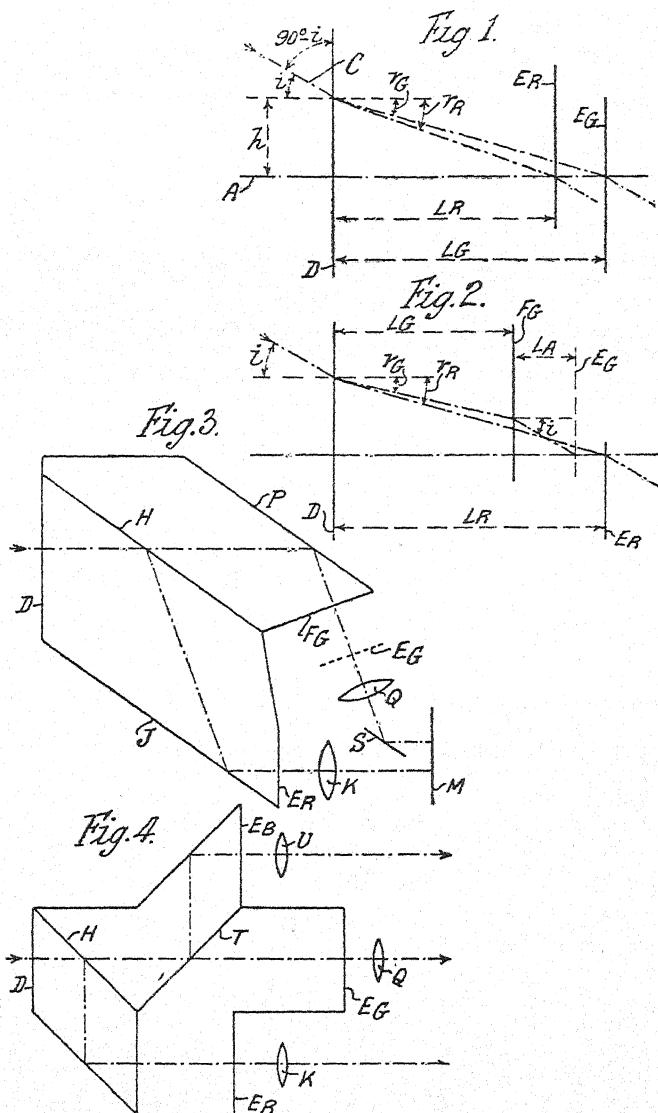


FIG. 287.—E.P. 427,983 of Adam Hilger Ltd. and J. H. Dowell.

example, in colour cinematography of the kind in which two images are formed side by side or one above the other in the space normally filled by one image, a lens of 1.3/8 in. focus would be used in most cases. With such a lens the difference

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in magnification between the two images for a system in which the images are exactly equal at an angle of 6° from the axis would not exceed 0.000,003 in. between the axis and 6° , and from 6° to 12° the difference would increase (with the opposite sign) to 0.000,04 in. for an object at 3 ft. distance.

Alternatively, while the prism is still made all of one kind of glass, the path of one colour image may be made shorter than is required by the above formula, the length of path then being made up by an air space; that is, instead of placing the lenses at the same distance behind the exit prism faces as would be the case for equal optical path lengths at a given angle of incident light, one of the lenses would be placed further away so that

$$L_R \tan r_R = L_G \tan r_G + L_A \tan i,$$

where L_A is the path length in air for the same wavelength as for L_G , i.e. the distance the lens is set back as compared with the lens for colour R.

Fig. 2 (Fig. 287) represents this case, in which an air path is included for the colour G. The actual exit face from the glass for colour G is now F_G , but the effective exit face is the plane E_G . The diagram clearly shows for this case how the last-mentioned formula is obtained.

By way of example, the data for a two-colour prism will be worked out. The prism may be of the form shown in Fig. 3, and be composed of one kind of glass having the following optical values:

N_G	N_D	N_F	N_{G1}
1.5094	1.5118	1.5175	1.5231

The prism is planned for transmission of light of mean wavelength 6,300 for the R image, the value of N_R being 1.5103, and the light for forming the G image is of mean wavelength 5,000, for which the corresponding value of N_G is 1.5165.

The prism is made up of two pieces cemented together, the joining surface H being partly silvered in known manner so as to reflect a desired percentage of the light and transmit the remainder.

The axial beam is indicated in the drawing, meeting the entrance face D perpendicularly. The light reflected at the surface H passes on to the reflecting surface J, where it is reflected in a direction parallel with the original direction of the light, and travels on to pass out at the exit face E_R of the prism. It is then focused by the lens K on the film M.

The transmitted light passes on to the reflecting surface P, by which it is reflected to the exit boundary F_G of the prism. This light is focused by the lens Q on the film M, a mirror S being interposed to bring the beam of light parallel with the other and to make it similar as regards left and right. The dotted line E_G is at the same distance from the lens Q as the exit face E_R from the lens K. Thus the distance from the face F_G to the plane represented by the line E_G is an air space, as indicated by L_A in Fig. 2.

The value of L_R for the lower prism is 5.30 in., and we assume the prism is to be made correct for an angle of 6° . From the formula

$$L_R \tan r_R = L_G \tan r_G + L_A \tan i$$

$$\text{we obtain} \quad 5.3 \tan r_R = L_G \tan r_G + L_A \tan 6^\circ$$

$$\text{or} \quad 0.36769 = (L_G \tan r_G + L_A \tan 6^\circ).$$

The value of L_G is obtained by trial by allotting values to L_A and calculating the corresponding value of L_G . By so doing we find the value $L_A = 0.5523$ and $L_G = 4.4816$. Inserting these values and calculating the value of

$$L_R \tan r_R - (L_G \tan r_G + L_A \tan i)$$

for other angles of incidence, we obtain the error in lateral shift, and dividing this amount by the magnification of the system—that is, the distance of object from the lens divided by the distance of image from the lens—we obtain the error in magnifica-

tion between the two images at the angle i . This works out in inches as follows for an object at 3 ft. and 4 ft. distance respectively:

i		3 ft.	4 ft.
1°	.. ..	-0.000,0011	-0.000,0009
2°	.. ..	-0.000,0019	-0.000,0015
3°	.. ..	-0.000,0029	-0.000,0022
4°	.. ..	-0.000,0027	-0.000,0020
5°	.. ..	-0.000,0019	-0.000,0015
6°	.. ..	0.000,0000	0.000,0000
9°	.. ..	+0.000,0124	+0.000,0094
12°	.. ..	+0.000,0412	+0.000,0310

The + sign indicates that the image of colour R is the larger.

It will be noticed that all the residual errors are amply within practical requirements. If, however, the errors at the angles 9° and 12° were considered too large, they could be reduced by correcting the prism for an angle greater than 6°, but there would of course be an increase in error at smaller angles.

As a further example a three-colour prism will be worked out. This may be of the form shown in Fig. 4 (Fig. 287). In this prism light enters at the face D and is first divided in known manner at the dividing face H and the transmitted light is again divided at the dividing face T in the desired proportion, so as to obtain three images, which would be formed by the lenses K, Q, and U all situated the same distance behind the respective exit faces E_R , E_G , and E_B .

Assuming the prism is to be constructed of one kind of glass having the same optical properties as the example for the two-colour prism of Fig. 3, with light of wavelengths 6,300 and 5,000 forming the R and G images respectively, and that the light for the third image B will be of mean wavelength 4,046, the corresponding value of N_B is 1.5217.

In this case we assume all the paths will be of glass, corresponding to the diagram of Fig. 1, and that the path L_G will be 6 in. If as before the prism is to be corrected for an angle of 6°,

$$L_R \tan r_R = L_G \tan r_G = L_B \tan r_B,$$

from which

$$L_R = \frac{L_G \tan r_G}{\tan r_R} = 5.9754,$$

$$L_B = \frac{L_G \tan r_G}{\tan r_B} = 6.0207.$$

Calculating for other angles, the following errors of magnification compared with the G images are obtained, for an object at 3 ft. and 4 ft. respectively, calculated exactly as before

		3 ft. R.	3 ft. B.	4 ft. R.	4 ft. B.
3°	..	0.000,0000	0.000,0000	0.000,0000	0.000,0000
6°	..	0.000,0000	0.000,0000	0.000,0000	0.000,0000
9°	..	-0.000,0004	+0.000,0008	-0.000,0003	+0.000,0006
12°	..	-0.000,0016	+0.000,0019	-0.000,0012	+0.000,0015

The sign indicates the picture magnification relative to that of the green. Here again it will be seen that the residual errors are of no practical significance.

It will also be clear that one or both paths could be made up in either case of glasses of different refractive indices, that is, the prism common to both colours in a two-colour camera could be of one kind of glass and the prisms individual to the two colours of another kind of glass. In other words the selection of the glasses

is made in the present case solely on the basis of length of path accepting the refractive indices of any glasses which may be available, whereas in our prior specification both path length and refractive index were to be adjusted to secure the desired result.

The procedure of the present invention can also be used with lenses of different focal length, provided such difference in focus is small, by making the optical paths traversed by the light of the various colours of such length as to compensate for the small difference in magnification of the corresponding lens. In this case account must also be taken of the magnification of distant images as well as near images, since the magnification of the lenses alone would be different for distant objects in proportion to the focal length.

The procedure will be outlined for the case of a two-colour system.

Suppose the lens corresponding to the path whose refractive index is N_o has a slightly greater focal length than that corresponding to N_r . Consideration must first be given to what range of focus will be most useful for the purpose in view, and the mean position of the focal plane determined, that is the distance from the lens at which the image will be formed, which can be computed from the formula $\frac{1}{V} = \frac{1}{F} - \frac{1}{U}$, where F equals the focal length of the lens, U the equivalent distance from the lens to the object in air, and V the distance from the lens to the image.

Since the magnification of both images must be the same,

$$\frac{U_o}{V_o} = \frac{U_r}{V_r}$$

From the above relationship it is also clear that

$$\frac{V_o}{F_o} = \frac{V_r}{F_r}$$

or otherwise expressed

$$\frac{V_o}{V_r} = \frac{F_o}{F_r} = \frac{U_o}{U_r}$$

therefore

$$U_r = \frac{F_r}{F_o} U_o$$

If we first assume a value for U_o equal to the mean distance of the object, we can then calculate the corresponding distance U_r , the equivalent distance from the object to the lens in air.

Also, since the difference in object size for equal angle of incidence i must be equal to the difference of lateral shift for each of the paths, we have

$U_o \tan i - U_r \tan i = L_o \tan r_o - L_r \tan r_r$
from which we obtain

$$L_r = \frac{L_o \tan r_o - U_o \tan i \left(1 - \frac{F_r}{F_o}\right)}{\tan r_r}$$

If a value is assumed for L_o convenient to the prism design, we can therefore determine the corresponding value for L_r . Then the errors corresponding to smaller and larger values of i should be computed, both for the mean focal position and for the extreme range of the focus decided upon, so that the degree of correction obtained can be determined throughout the whole range required.

Considering the matter in general, it will be noticed that since

$$U_r = \frac{F_r}{F_o} U_o$$

it is clear that the object size for equal angle of incidence is also proportional to

$$\frac{F_r}{F_o}, \text{ that is, equal to } \frac{U_r \tan i}{U_o \tan i}$$

We can therefore say that the sum in every light path of the total lateral shift between the common entrance face and the lens and the lateral displacement over the air distance from the object to the common entrance face is directly proportional to the focal length of the lens associated with that light path.

It will be noticed in the above that reference is made to the difference in object size for equal angle of incidence i . It can be shown that this difference in object size corresponds to the difference in image size resulting from the focal difference in the lenses, so that, for the same point on the object, images of equal size are obtained for a chosen angle i for one of the colours; but it will be clear that a ray coming from a point on the object at the chosen angle i for one colour will proceed to the lens of any other colour at an angle slightly different from i , but this slight difference of angle just compensates for the difference in focal length of the lenses.

It will also be clear that the arrangement first considered is a special case of the more general treatment just given. The lenses being of equal focal length, the sum mentioned will be equal for all paths. Moreover, the lateral displacement over the air distance from the object to the common entrance face is now equal, since the angle of incidence is the same for all colours. Hence the other term of the sum must be the same for all colours, viz. the lateral shift between the common entrance face and the lens or some point similarly situated on each path in relation to the lens.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:

1. In or for a camera for colour photography a light-dividing prism system in which the lengths of path traversed by the light destined to form the images of different colours are so selected that for a ray incident at a chosen angle of obliquity the total lateral shift relative to the taking lenses is the same for all the different coloured images, irrespective of the reduced optical path length on the axis.

2. A prism system as claimed in Claim 1 in which the path traversed in glass by light for one image corresponds as regards equality of lateral shift to a path partly of glass and partly of air traversed by light for another image, the paths being reckoned from the common entrance face of the prism system to points equivalent in relation to the respective lenses.

3. A prism system as claimed in Claim 1, in which the air paths of the light relative to the lenses for all images are equal, so that the corresponding parts of the different paths are solely in the glass.

4. A prism system as claimed in Claim 1, 2 or 3 in which one kind of glass is used for all the paths.

5. A prism system as claimed in Claim 1, 2 or 3 in which two or more kinds of glass of different refractive indices are used in one or more of the different paths traversed by light of the different colours.

6. A prism system modified in relation to those claimed in any of Claims 1 to 5 in that the path lengths are slightly adjusted from the values computed according to those claims so as to compensate for small differences in focus of the corresponding lenses.

7. In or for a two-colour camera a light-dividing prism system substantially as described with reference to Fig. 3 of the accompanying drawings.

8. In or for a three-colour camera a light-dividing prism system substantially as described with reference to Fig. 4 of the accompanying drawings.

Dated the 2nd day of October, 1934.

Projection prism erecting systems for use in additive projection of pictures, in which the images are arranged side by side, the width of the pictures being along the length of the film, are described in E.P. 394,385 of Adam Hilger Ltd. and J. H. Dowell. Registration

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is effected by movement of one of the reflecting surfaces or of a group of them, and the rays from the companion images are completely

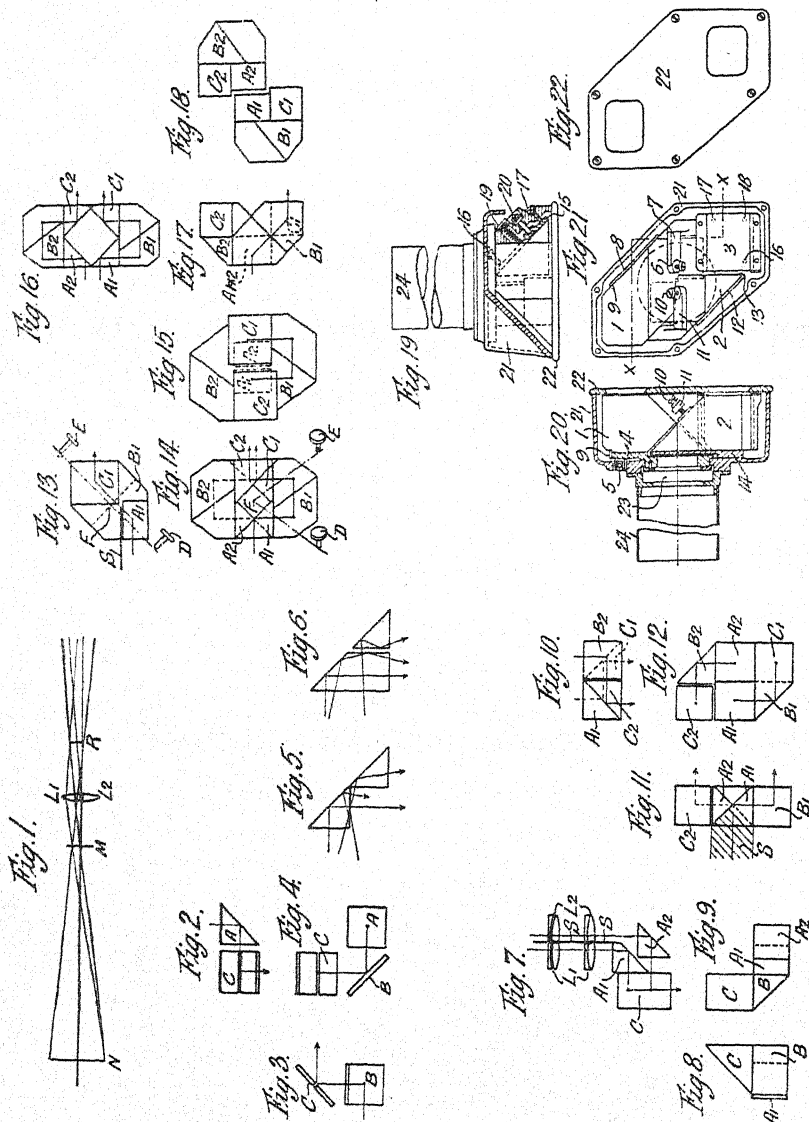


FIG. 288.—D. Daponte's E.P. 394,385.

separated before registration by reflecting surfaces so displaced out of coplanar setting that a dividing screen can be brought right up to the point where the optical paths of the beams diverge from one another. Figs. 10-12 (Fig. 288) show one form for projecting pairs of 554

images, in which each light beam undergoes three reflections at the cathetus faces of right-angle prisms, Fig. 10 being a plan, Fig. 11 a side view, and Fig. 12 a front view. The rays from the left-hand image are incident on a prism A1 by which they are reflected down to a prism B1 reflecting them to the right on to a prism C1 by which they are reflected towards the projection screen. The rays from the right-hand image are reflected upwardly by the prism A2, then to the left by the prism B2, and forwardly by the prism C2. The prism C2 is separate from the others and is adjustable about two axes at right angles to register the projected images on the screen; the other five prisms are cemented together. Interference between the two images is prevented by extending the dividing screen S so that it passes between the prisms A1, A2. The displacements of the two beams produced by this system are symmetrical in relation to the axes of the projector, and are small enough to allow the light to pass through an ordinary projection window. A mounting for this system is described. Figs. 13-15 are views similar to Figs. 10-12 of another system in which each beam undergoes four reflections so that the system can be used for the projection of film taken by a camera operating on its side and not fitted with erecting device, the film being used in the projector the normal way round, *e.g.* emulsion side towards the condenser. This system comprises two units, one for each image, each comprising three right-angled prisms A1, B1, C1 and A2, B2, C2. Each prism B1, B2 is arranged so that its cathetus face serves as a light entrance and exit surface, and the light is reflected by each of the other two faces. Light from the left-hand image enters the prism A1 and is reflected down into the prism B1, the roof edge of which is below the cathetus face and inclined at 45° to the axis of the lens system. After two reflections by the prism B1 the light enters the prism C1, by which it is reflected towards the screen. Light from the right-hand image undergoes similar reflections by the prisms A2, B2, C2. With this system the emergent rays are in the same horizontal plane as the incident rays. Registration is obtained by making the unit A1, B1, C1 adjustable, the adjustment indicated in Figs. 13 and 14 being about two axes at right angles intersecting at the point F. The screen S extends between the prisms A1, A2.¹

E.P. 346,454 of D. Daponte deals with the same subject-matter (Fig. 289). The principal claim is:

An optically folded projecting system for combining side-by-side images on the film into a single image on the screen having an adjustable split mirror placed in or near to the plane in which the image of the condenser is formed by the projection lens and in combination with a split projection lens.

¹ This beam-splitter was used by the British Realita Syndicate Ltd. in place of the Francita beam-splitter (see page 279). A collimator was placed in front of the whole system.

COLOUR CINEMATOGRAPHY

3F. Two images of normal size disposed vertically one above the other.
Pull-down normal and each picture exposed twice—i.e. once in each gate.

The Hillman camera will be referred to briefly under this heading (e.g., 3F). London Film Productions Ltd. was closely associated

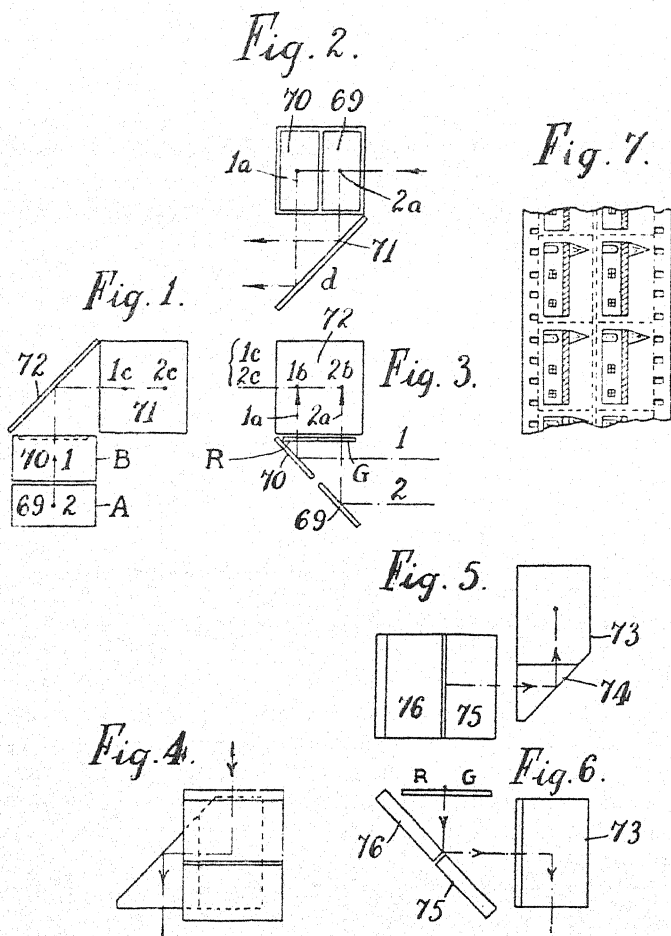


FIG. 289.—D. Daponte's E.P. 346,454.

with Colourgravure Ltd., which was formed to exploit the Hillman patents. The camera was never used for a commercial film. The arrangement consisted of two lenses, one above the other (Fig. 290), the light being divided by polished metal mirrors, the upper one being perforated

(E.P. 404,307, 1933). The gate had two standard openings, two frames being exposed simultaneously through the standard two-colour filters Wratten Nos. 28 and 40A. The filters were mounted in an oscillating member (Fig. 291). The film was moved downwards one frame at a time and the upper picture received a second exposure through the same filter after having arrived in the lower frame. Thus every image was exposed first in the upper gate and immediately after in the lower gate. The rotation of the shutter was in the opposite direction to the travel of the film, and the second exposure of a negative actually began before the first exposure of the following negative. It was asserted that the different motion phases compounded in any one image were the result of half-exposures only, and that there was therefore very little fringing. In practice the time-parallax was distinctly visible in

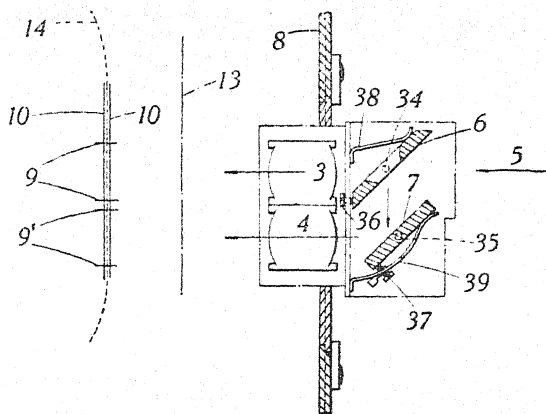


FIG. 290.—A. G. Hillman's E.P. 404,307, 1933.

projected pictures and became serious in the case of quick movements within 20 ft. of the camera.

In E.P. 414,065 (Hillman, A. G., Johnson, G. H., and Colour-gravure Ltd.) the claims are:

1. Process for the production on a negative band of colour constituent images (negatives), forming a continuous series, the process having the following characteristics:

- (a) Each negative is the result of two or more exposures through the same or similar colour filters.
- (b) Each negative (other than the extreme negatives of the band) is exposed to the same beam as the preceding negative and also to the same beam as the following negative, each of such beams being divided by appropriate means for this purpose.

COLOUR CINEMATOGRAPHY

2. Process as in Claim 1, having the further characteristic that the beam-dividing means do not involve the passage of the beam through any refracting medium.

3. Process as in Claim 1 or Claim 2, in which the exposures are effected by means of a shutter revolving so that the edges of the aper-

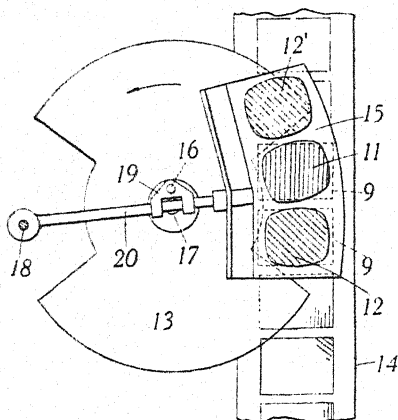


FIG. 291.—A. G. Hillman's E.P. 414,059.

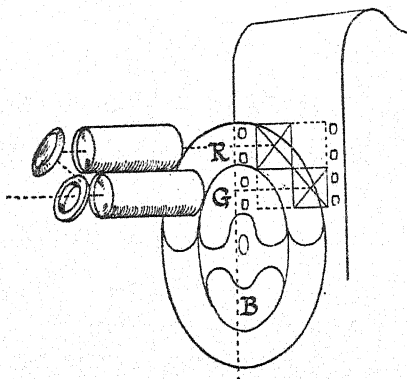


FIG. 292.—E.P. 419,894.

tures are moving at the moment when they effect exposure, in a direction contrary to that in which the band moves through the camera, so that the exposure of each negative commences before the exposure of the succeeding negative, etc.

E.P. 414,059 of the same patentee dealt with means for rotating for adjustment the metal mirrors in front of the objectives and the detailed design of the oscillating filter sector (Fig. 291). See also 558

E.P. 478,500, 483,079, and 478,501. The latter describes Hillman's projection system.

FURTHER HILLMAN PATENTS

E.P. 483,817

E.P. 494,333

E.P. 483,819

E.P. 494,334

E.P. 483,820

The French Francita camera, with which pictures were taken of the Coronation of George VI, was designed to record miniature images within the space of a normal frame (see Chapter II) (E.P.

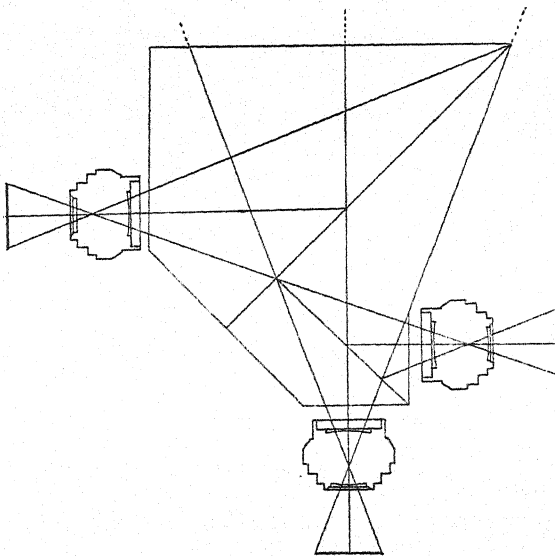


FIG. 293.

419,894), in which the red and green records were exposed simultaneously and the film moved half a frame and the blue exposure then made. The reflectors in this camera were precisely like those in the Hillman camera, being in front of the pair of objectives, made of metal and one of them perforated (Fig. 292).

3G. Disposed at 90° to each other, or at some other angle. Separate gates and normal pull-down.

Fig. 293 represents an arrangement of doubtful practicability designed merely to illustrate Class 3G.

3H. Rotating mirror divider in front of two or more lenses.

The Technicolor patent E.P. 350,856 proposed a rotating apertured reflecting shutter in front of two objectives at right angles to each other (Fig. 294).

CLASS 4

4. Two or More Lenses behind a Negative Divergent Lens. The Positive Lenses Photograph a Virtual Image produced by the Negative Lens

R. Berthon and M. Audibert [4] patented a method of obtaining a virtual image by means of an anterior lens and prisms or mirrors. This idea was further improved upon in E.P. 17,023, 1913. In F.P.

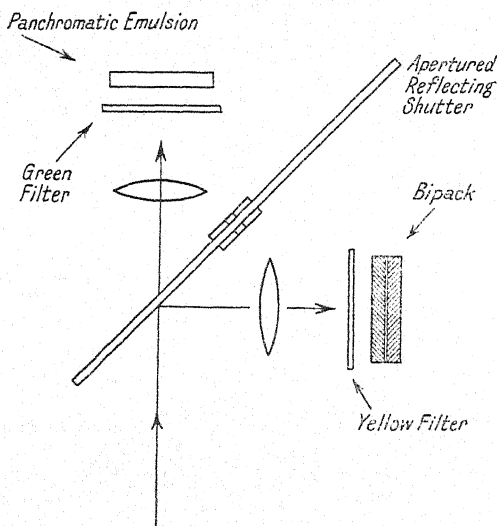


FIG. 294.—Technicolor, E.P. 350, 856.

458,040 Audibert proposed to use a negative front lens forming a virtual image and three positive lenses in rear to form coplanar images. T. Thorier [5] stated that this arrangement considerably reduced parallax because the virtual image taken up by the positive lenses has but little depth of field. If f is the focal length of the divergent lens all the field included between a distance d and infinity is compressed into a space practically equal to f^2/d . And calling F the foci of the posterior lenses, R the ratio of the final image to the aerial image, the distance D of the nearest point which can be satisfactorily taken is found from $f/F(2+R+1/R)$. The ratio system of the complete system is $1/n(R+1)$, in which $1/n$ represents the ratio aperture of the posterior lenses. It is easy by making $R < 1$ to increase the luminosity of the lenses.

In E.P. 355,835 this principle was further modified (Fig. 295). C, D, is a divergent objective. O^1 , O^2 , O^3 , are lenses producing three images on the sensitive surface M. The divergent objective has its nodal points N^1 , N^2 , in advance of the lenses, so that the aperture of the objectives O^1 , O^2 , O^3 , can be increased or the total length of the apparatus reduced. The focal lengths of lenses C and D are respectively 250 and -90 mm., and these lenses are mounted so as to be almost in contact.

The Audibert optical system may have certain minor defects from an academic point of view, but these would probably turn out to be less than the errors encountered in three-colour superposition printing. There would probably still be found to be a small amount of parallax, even taking into consideration the shallow depth of field of the virtual image. Other defects, such as coma, might also be present.

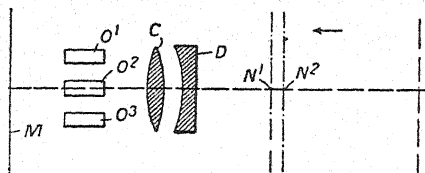


FIG. 295.

CLASS 5

5. Two or More Lenses behind Inclined Glass Plates

In E.P. 435,222, A. J. Arnulf, a French inventor, proposed to avoid parallax by using inclined parallel glass plates in front of two or more objectives. The suggestion is original, and it might provide a satisfactory means of eliminating parallax.

The principle underlying the invention will be described by way of example with reference to the accompanying drawings, wherein Figs. 1 to 5 are explanatory diagrams (Fig. 296).

It is known (see Fig. 1) that a plate having parallel faces receiving at the angle i an incident beam SI does not deflect this beam but displaces it laterally by a distance d such that

$$d = E \left(\frac{1 - \cos i}{\sqrt{n^2 - \sin^2 i}} \right) \sin i,$$

E being the thickness of the plate, i the angle of incidence, and n the refractive index of the plate.

Or, approximately, when i is equal to or smaller than 10° ,

$$d = E \left(1 - \frac{1}{n} \right) \sin i.$$

It results from this that if a plate having parallel inclined faces is placed before the objective of a camera, the rays incident at the same angle i from all the points of the landscape, whatever be their distance, are displaced laterally by the quantity

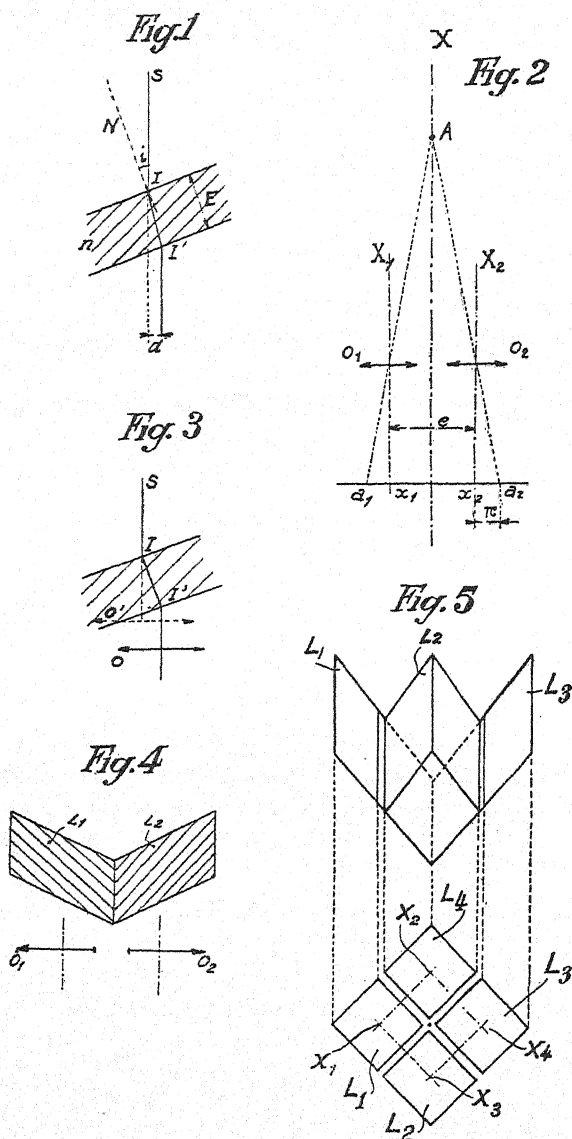


FIG. 296.—E.P. 435,222 (A. J. Arnulf).

d. It results from this that the corresponding displacement δ on the plate or the film will be

$$\delta = \frac{df}{D}$$

D being the distance of the point considered and f the focal length of the objective.

COLOUR-CAMERAS AND BEAM-SPLITTING SYSTEMS

It is seen that this displacement δ on the film is greater as the object is nearer. It is zero when D is infinity.

There is thus the possibility of displacing laterally the images of points in planes positioned at a finite distance from the objective in relation to those of points at an infinite distance which remain fixed, the displacement being greater as the distance D of the plane considered is less.

This phenomenon is utilized according to the invention in order to correct the parallax.

Optical devices are already known comprising plates of glass having parallel faces combined with objectives. But the employment of these glass plates has for object in these devices either the correction of the distance of the optical axes of the objectives for the examination of photographic views or of compensating in a cinematographic projection the continuous displacement of a film. In other words, in these devices the plates of glass having parallel faces are used at variable inclinations in order to obtain the same displacement of images of objects positioned in the same plane. On the contrary, in the present invention the glass plates having parallel faces are used at a fixed angle in order to create different displacements of the images of the various planes unequally distant from the objectives. This principle will appear more clearly in the following description.

In Fig. 2 π indicates the parallax of the point A in relation to an infinitely distant point positioned in the same direction. In order to suppress this parallax, a plate having inclined parallel faces is placed before the objective O_2 , which will give to the point A in the convenient direction a deviation sufficient to return the image a_2 to x_2 . This deviation will be such that $\delta = \pi$.

If f is the focal length of the objectives, e the distance between the axes of these objectives, and D the distance from the point A to the plane of the objectives, then

$$\pi = \frac{ef}{2D}$$

By equalizing the values δ and π ,

$$\frac{d}{Df} = \frac{ef}{2D}$$

whence

$$d = \frac{e}{2}$$

or

$$e = 2d.$$

There is thus obtained a very simple condition for eliminating the parallax, a condition which is independent of the focal length of the objectives. This is explained practically by the fact that when the distance between the axes of the objectives has been chosen, the same system of parallax correction plates might be used whatever be the focal length of the objective system employed.

It will be noticed, likewise, that this condition is independent of the distance of the point considered.

It results from this that if the parallax correction has been effected for a given plane of the object space, it will be effected for all the other planes.

The effect produced by the plate having parallel faces in the suppression of the parallax may be expressed under a somewhat different form. The plate having parallel faces has for effect to produce a virtual displacement from O to O^1 of the inlet aperture of the objective. In order to suppress the parallax, the plates will be chosen so that the optical axes of all the objectives are virtually brought into coincidence.

One form of practical device, in the case of two objectives, is illustrated in Fig. 4. Each objective O^1 or O^2 is provided with a plate L_1 or L_2 , the effect of these plates being to effect a virtual displacement towards each other, and by the same amount, of the two axes. The adjacent faces of the two plates are blackened and joined together.

In the case where a number of objectives, greater than two, are employed, the plates will be disposed as described hereafter.

The optical axes of the monochromatic objectives are arranged to pass through

COLOUR CINEMATOGRAPHY

the apices of a polygon, having 3, 4, etc. . . . n sides, according to whether the number of objectives is 3, 4, etc. . . . n . All the objectives will be provided with identical plates, these plates being disposed in such a way that the optical axes of these objectives are brought into virtual coincidence at the centre of the circle circumscribed on the foregoing polygon.

The lines of greatest inclination of the plates will be parallel to the lines which join the apices of each polygon to the centre of the circumscribed circle.

This rule is not absolute. The plates may have smaller thicknesses or smaller inclinations than those necessary completely to correct the parallax.

Likewise, the plates may have greater thicknesses or greater inclinations than those necessary to correct the parallax, which will have for effect to invert this parallax.

Likewise, a system of plates may be provided, the inclination of which to the optical axes of the objectives is variable, the inclination of all the plates remaining identical among themselves. This device has for object to give the possibility of varying the parallax whilst taking the picture, this variation being capable of giving artistic effects.

Fig. 5 illustrates one form of the invention employing four plates, L^1 , L^2 , L^3 , L^4 in the form of prisms. The upper part of Fig. 5 shows these plates in elevation and the lower part in plan. The arrangement shown in Fig. 5 is adapted for the correction of the parallax for a system of four objectives, the axes X^1 , X^2 , X^3 , X^4 of which are arranged to pass through the corners of a square.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:

1. A device for taking photographic or cinematographic views in colours wherein plates having inclined parallel faces are disposed before the view taking objectives so as to effect a virtual displacement of the axes of the objectives, whereby the parallax effects are reduced, eliminated or increased, substantially as set forth.

2. A device as claimed in Claim 1 wherein two objectives are employed and two plates having inclined parallel faces and inclined symmetrically in relation to the axes of these objectives, substantially as described.

3. A device as claimed in Claim 1 wherein more than two objectives are employed and the axes of these objectives are arranged to pass through the apices of a polygon having a number of sides corresponding to the number of objectives, all the objectives being provided with identical plates disposed so as to effect a virtual displacement of the axes of these objectives to or from the centre of a circle circumscribed on the said polygon, or of making them coincide with the said centre.

4. A device for taking photographic or cinematographic views in colours and having for object to reduce, to eliminate, or to increase the parallax effects of the view taking objectives, constructed, arranged, and adapted for use substantially as described with reference to and as illustrated in the accompanying drawings.

Dated this 18th day of August, 1934.¹

CLASS 6

For an example of Class 6 see page 273.

BEAM-SPLITTER PATENT ANALYSIS ACCORDING TO CLASSIFICATION (UNITED KINGDOM PATENTS ONLY)

Class 1.

A	B	C	D
130,002	204,745	100,021	101,972
136,595	350,112	110,595	127,308
237,941	475,415	141,368	131,422
373,429	472,468	450,673	194,971
407,287	503,222	464,637	340,973
492,673			347,946
466,528			

¹ Reprinted by permission of the Controller of His Majesty's Stationery Office.

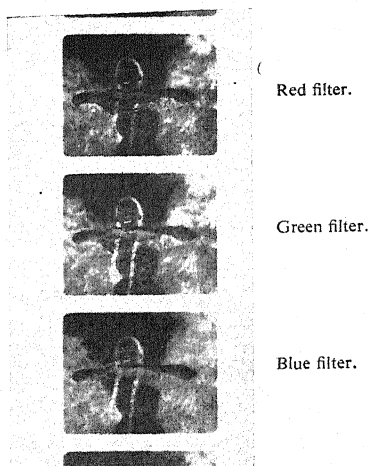


FIG. 297.—Three-colour negative made with Vinten Model H. camera at 72 exposures per second (p. 565).

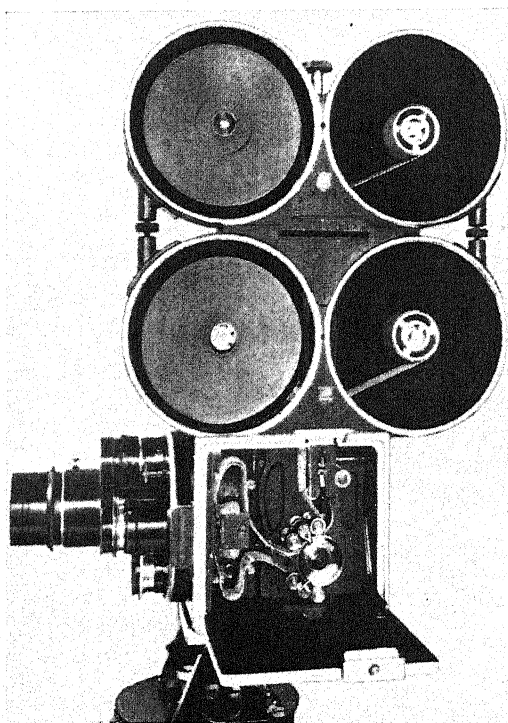


FIG. 298.—Bell and Howell camera with bipack magazine and special gate.

(Facing p. 565)

COLOUR-CAMERAS AND BEAM-SPLITTING SYSTEMS

Class 1—continued.

E	F	G
100,082	1,073 1915	211,147
503,222	2,463 „	237,259
	471,102	312,248
		319,195
		324,989
		342,036
		469,359
		441,907
		474,800
		509,269
		555,167
		556,426

Class 2

7,514 1918
25,908 1906
13,150 1912
322,801

Class 3

A	B	C	D	E	F	G
147,767		7,659 1915	199,044	346,406	404,307	350,856
153,325		13,042 „	206,820	346,454	414,065	
276,591		16,810 „	257,547	349,107	414,059	
		18,611 „	257,548	388,754	419,894	
			257,549	394,385	478,500	
			398,100	427,983	483,079	
			427,983		483,817	
			437,414		483,819	
			459,664		483,820	
			473,782		494,333	
					494,334	

Class 4

151,385
209,041
355,835

Class 5

435,222
470,653

Class 6

195,663
209,041
274,683
385,141

THE "72" METHOD

This method of recording colour negatives was revived by Gasparcolor Ltd. in England in 1935. It was used for a time with some measure of success (Fig. 297).

The visibility of a fringe is determined by the fact that if its dimensions are such as to subtend less than an angle of 1' 30" at a given distance it will be impossible to distinguish. The following formula will be found useful:

Angle in seconds

$$= \frac{\text{Height (or width) of fringe (or element)}}{\text{Distance}} \times 206,265$$

COLOUR CINEMATOGRAPHY

so long as the distance is at least 100 times the height (or width) of fringe or element in question.

Therefore:

$$\text{Height} = \frac{\text{Distance} \times \text{angle in seconds}}{206,265}$$

Thus, say 1' 30" is the limit of resolving power of the eye, and assume distance of screen from the front row is 25', the limiting fringe in inches would be

$$\frac{(25' \times 12) \times 90'' \text{ (seconds of arc)}}{206,265} = \frac{27,000}{206,265} = 0.13'' \text{ (inches).}$$

Suppose the screen to be 20' in width, then the magnification would be:

$$20' = 6,000 \text{ mm.} \quad \frac{6,000 \text{ mm.}}{22 \text{ mm.}} = 273 \text{ (for 35-mm. film).}$$

Therefore the actual dimensions of the fringe or element in question on the film must be

$$\frac{0.13''}{273} = \frac{1''}{2,000} \text{ approximately.}$$

TABLE 63

Screen Width.	Linear Magnification.	Fringe on Film.	Angle Subtended at 50 ft.	Angle Subtended at 25 ft.	Fringe on Screen.
25'	340 ×	$\frac{1}{2000}''$	57"	1' 54"	$\frac{1}{3}''$
25'	"	$\frac{1}{1000}''$	1' 54"	3' 48"	$\frac{1}{3}''$
25'	"	$\frac{1}{500}''$	3' 48"	7' 36"	$\frac{1}{3}''$
25'	"	$\frac{1}{250}''$	5' 42.6"	11' 25"	1"

References

- (1) E.P. 2,973 (1876); *Brit. Journ. Phot.*, 24 (1877), p. 152.
- (2) RENDALL, H. E., *Phot. Journ.*, 64 (1924), p. 390.
- (3) Technicolor Motion Picture Corporation, E.P. 398,339.
- (4) BERTHON, R., and AUDIBERT, M., E.P. 24,809 (1911).
- (5) THORIER, T., *Phot. Rev.*, 32 (1920), p. 49.
- (6) *Jahrbuch*, 16 (1902), p. 543 (*Eder's Jahrbuch der Photographie und Reproduktionstechnik*).
- (7) COOTE, JACK H., "New Three-Color Camera," *Journ. Soc. Mot. Pic. Eng.*, 50 (June 1948), p. 543
- (8) BREWSTER, P. D., "Three-Color Subtractive Cinematography," *Journ. Soc. Mot. Pic. Eng.*, 16, No. 1 (Jan. 1931), p. 49.
- (9) STAAL, G., and JERNY, J., "Cameras for Shooting Three-Colour and Sound—ZKS.1," *Kino. Photo. Chem. Indust.*, 2 (1937).
- (10) FRIDMAN, V. M., "The Preparation of Three-Colour Positives with Dichromated Gelatine," *Kino. Foto. Khim. Prom.*, 5 (Oct., 1939), p. 48.
- (11) FRIEDMAN, J. S., "History of Colour Photography," Boston, (1945), pp. 34-65.

Bipack

AS has been stated in the historical summary, the bipack was suggested by Ducos du Hauron in F.P. 250,862, 1895, and by A. Gurtner in E.P. 7,924, 1903—the latter patenting the idea of combining two plates face to face, the plate nearer the lens being coated with a slow chloride, or chloro-bromide emulsion sensitive to blue and violet, the emulsion being stained a deep orange, the rear plate was to have an emulsion sensitive to orange and red. Other bipacks followed.

The bipack has played a very important part as a means of recording negatives for colour cinematography. G. Battistini patented the arrangement of bipack and a single film in two gates at right angles to give three-colour negatives (E.P. 873, 1915). W. Buchanan-Taylor and others patented a similar arrangement in E.P. 12,469, 1914. The camera contained a semi-transparent mirror to reflect the light to gate A accommodating one film, and to transmit the light to gate B accommodating two films, the bipack.

A. Hamburger and W. E. L. Day in E.P. 136,595, 1918, patented the same "semi-dialyte" type of camera. Two films sensitive to blue and green respectively ran face to face through one gate. The other film was red sensitive, passing through a second gate at right angles. The patent is only for the feeding mechanism. Hamburger never used this arrangement because he never perfected a three-colour printing process. The Debie camera which was made for his two-colour "Polychromide" process could be used for three-colour with minor modifications.

P. D. Brewster was one of the first to apply the bipack negative system for two-colour recording (E.P. 2,465, 1915), and he was one of the first, if not the first, to use registering pins in cameras and projectors (U.S.P. 1,359,024, 1920).¹

Nearly all the two-colour American processes mentioned in the chapter on subtractive processes used bipack for negative recording. Naturally, American emulsion manufacturers concentrated on the problem and ultimately Du Pont produced an excellent bipack under the trade name of "Dupac." The corresponding Eastman products are 35-mm. Special Negatives, *Bipack Orthochromatic, exterior*, Type

¹ See also W. v. D. Kelley, p. 214.

1234, and *Bipack Panchromatic*, Type 1235. The former consists of a red dye-overcoated orthochromatic film of medium speed with colour sensitivity and contrast balanced to daylight illumination. This is the front film to be used in combination with Type 1235 to make separation negatives of exterior scenes for two-colour printing processes. Eastman also make Type 1236, known as *Bipack Orthochromatic, interior*, which is an orthochromatic film with red dye overcoating, similar in use and purpose to Type 1234 above, except that its colour sensitivity and contrast are balanced for tungsten illumination at 3,200° to 3,400° K. Type 1235 is known as *Bipack Panchromatic, interior and exterior*. It is a panchromatic negative film balanced in speed and colour sensitivity for bipack work. It is always used in combination with one of the above orthochromatic films to make colour separation negatives of two-colour printing processes.

Both Bell and Howell and the Mitchell Camera Corp. studied the special camera requirements. Suitable magazines were designed and changes made in the gate. When bipack is used the focal plane is about 0.0045 in. further back from the lens than in the case of normal film, because, it must be remembered, that the front film is turned emulsion side away from the lens and in contact with the emulsion of the rear film. Then the question of perfect contact of the emulsion surfaces of the two films had to receive careful consideration. In the Mitchell camera four small rollers were introduced with satisfactory results. Bell and Howell place two of their normal black-and-white magazines one on top of the other (Fig. 298).

Bipack may be used in two ways for the recording of three-colour negatives. First, in any beam-splitter camera in which the beam is split into two, there being two gates. Bipack is exposed in one gate and a single film in the other.

Now in such an arrangement it is obvious that the bipack can be used to record either the blue on the front film and the red on the back film, or, alternatively, the green on the front film and the red on the back film. The latter choice is possible because the front film is an orthochromatic emulsion, and therefore sensitive to the green and blue light over the whole of these two trichromatic regions. The former arrangement, in which the blue light is recorded on the front film, was patented by Technicolor in E.P. 373,429, 1931. (For full description, see Chapter IV, p. 512.)

When used for three-colour in the above manner, if the blue is recorded on the front emulsion of the bipack, then no filter is used. The front emulsion is coated on its surface with a red filter excluding all light other than red from the rear panchromatic emulsion. On the other hand, if the green light is recorded on the front emulsion a yellow filter (minus-blue) is used. Naturally these filters are placed only in that part of the beam which has been directed towards the bipack. The bipack

can be placed either in the direct beam or in the diverted part of the beam.

These arrangements presuppose the construction of a bipack as hitherto manufactured, having a filter of some kind introduced between the orthochromatic front film and the panchromatic back film. Such a filter may be coated on the surface of the front emulsion or it may be partly embodied in the emulsion itself. The filter is generally a deep red-orange and is essential, otherwise blue or green light would reach the back panchromatic film and there be recorded. Technicolor

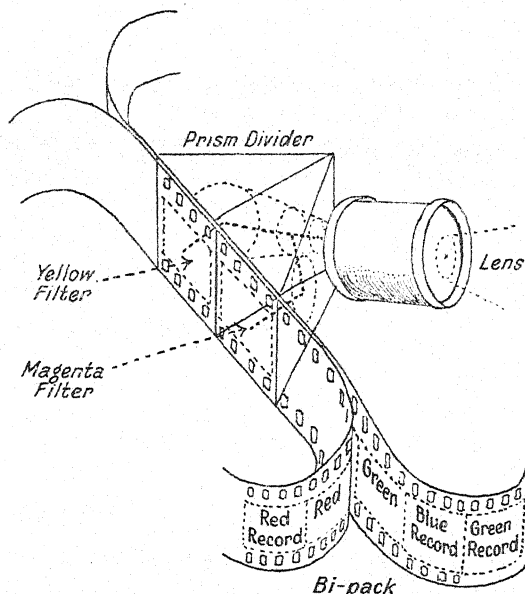


FIG. 299.—How Technicolor E.P. 349,318 could be used to obtain three-colour negatives on bipack. Film to be pulled two frames at a time.

claim an advantage in using a magenta filter in connection with a bipack, since they declare that the red filter incorporated in the bipack is subject to slight variation, and that this variation is smoothed out by the fact that the magenta filter with its sharply cut red absorption band stands in front of the bipack. However, the method is not at present in use. In other words, the claim is that the alternative method of using a yellow filter in order to get a green record on the front film and a red record on the back film would possess the disadvantage of yielding somewhat irregular results owing to the slight variations in the red filter of the bipack.

The second method is to record simultaneously or successively a magenta filter record and a yellow filter record on a bipack film (Fig.

299). By this method, if the records are made simultaneous and the pictures are full-size, we shall use four times as much negative film as black-and-white, because four frames are exposed at a time. It is thus an expensive solution of the problem. Also, if both exposures are made simultaneously, the camera mechanism would have to pull the film down two frames at a time. On the other hand, beam-splitters such as the Cinecolor (British) or Raycol would yield *four* miniature negatives on *two* frames. The patent granted to Colour Photographs Limited (E.P. 363,000), covered this method of taking three-colour negatives, applied in any case to the normal bipack (see below).

In E.P. 377,706 an interesting subtractive printing process is described in which a developed positive film is coated with a layer of gelatine containing a pigment or dye-lake and after drying treated with a bath corresponding to the well-known "Carbro" bleach. The coloured gelatine layer is thereby hardened in proportion to the presence of silver in the underlying positive layer by the compounds liberated by the bleaching process. Subsequently, the film is washed in hot water and thus a relief is formed. The gelatine of the underlying silver image may be hardened at any stage prior to the hot-water treatment, and, subsequently, the bleached silver is removed. Suitable baths for the bleaching and hardening process comprise: (1) chromic acid, potassium bromide, and potassium ferricyanide, or (2) copper chloride, potassium bichromate, and potassium bromide. Such a process has possibilities for two-colour films, and it might easily be combined with some further processing in order to obtain a third coloured layer.

E.P. 400,264 of D. A. Spencer and H. D. Murray is a very original proposal to combine additive and subtractive principles of colour synthesis. They proposed to use a beam-splitter device of the type which will give two images one above the other (as in Raycol, Cinecolor, etc.). The two images are recorded on *bipack*. This provides four negative images thus:

Neg. I. The Front Film Records.					Neg. II. The Back Film Records.				
Frame I	..	..	..	Blue	Frame I	..	..	..	Red
Frame II	..	..	..	Green	Frame II	..	..	..	Red

For frame I a magenta filter is used; for frame II a yellow filter. These negatives are printed on double-coated stock. The side printed from negative I is toned *primary red*. The other side printed from negative II is toned cyan (minus-red). These records are now projected through filters which are additively complementary and are of such colour and so adapted to the frames that *each filter will absorb those rays of light which are transmitted by the primary colour a record which is absent from that frame.*

This is a very ingenious conception, but it possesses serious commercial disadvantages. The projection system requires a special rotating disc on the projector. No really satisfactory beam-splitter has been designed which will give two full-sized frames one above the other. Lacking such an optical unit recourse would have to be had to sub-

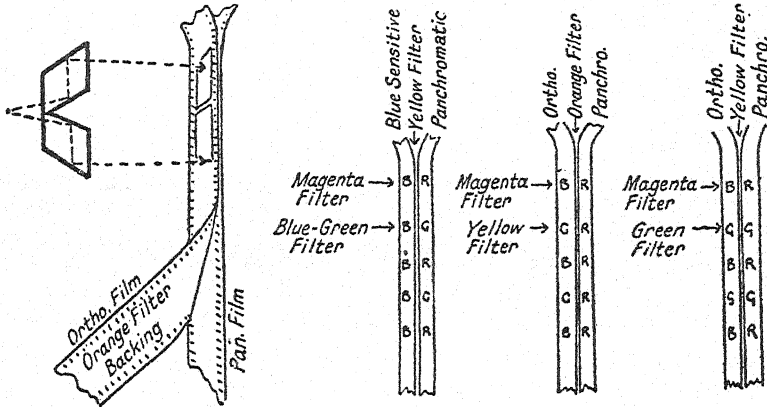


FIG. 300.—Three-colour negatives obtained with beam-splitter camera using bipack, E.P. 363,000 (Spencer).

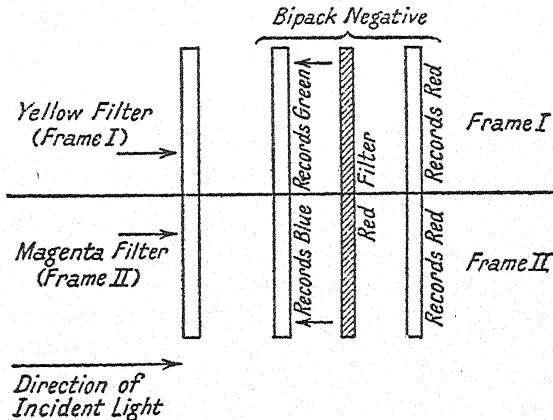


FIG. 301.

standard images such as are obtained in the Raycol and Cinecolor (British) cameras. Finally, it is very doubtful if flicker could be avoided, since at normal projection speed there would be twelve alternating frames having slight colour differences which would certainly be perceptible to the eye.

The above patentees are responsible for an important bipack patent (E.P. 363,000) which claims the method for obtaining three-colour

negatives by means of a single exposure with a beam-splitter camera on bipack material of the normal variety, namely, having the panchromatic emulsion on the rear film. Adjacent frames simultaneously recorded are taken through yellow and magenta filters respectively (Figs. 300, 301).

Further possible alternative arrangements are described.

Du Pont Bipack

Du Pont in B.P. 505,861 describe a bipack from which three separation negatives can be obtained by a sequence of operations applied to the rear element. The bipack consists of a front blue-sensitive yellow-dyed element single-coated of the normal type. The rear element carries a two-layer coating, the front layer being green sensitive and the back layer red sensitive. Between the two layers is a red filter layer. The yellow dye in the front emulsion and the red filter interleaving layer are destroyed in the developer.

After development of the rear element a positive intermediate print is made from the combined green and red negative records. Next the double-layer negative is bleached and the top layer only is re-developed with a viscous developer. On fixation the bottom layer is eliminated. The intermediate positive made previously from the two-layer film is now used as a mask and a print made from the two combined. The resulting print will be a duplicate negative of the destroyed image which constituted the rear emulsion. We therefore now have three negatives. The front element of the bipack, the front negative of the double-coated rear element and a third negative derived in the manner described.

The claims are:—

1. The method described for the production of independent colour separation photographic records from two or more colour separation records inseparably superposed on the same support, characterized in that the elimination of one of the records is effected after the records have been developed to silver images, by bleaching all the records to convert them to silver salts, re-developing all but the innermost record by means of controlled development and finally dissolving away the undeveloped silver salts which formed the innermost record.

2. The method according to claim 1 applied to the processing of the multilayer element (or elements) of a bipack in which one support (or both) carries two superposed emulsion layers each sensitized to a particular colour range and in which the layers of both members of the bipack have been exposed simultaneously to form the original colour separation records.

Use of Bipack

Contemporary technical procedure in the employment of bipack is well described in a recent paper presented by John Boyle, A.S.C., at a

convention of the S.M.P.E. in October 1946, to which we are indebted for most of the information here given.

The following changes are necessary to convert the N.C. type Mitchell for bipack:

1. Move lenses towards the film (emulsion) plane a distance of 0.0045 in., then use normal calibrations for focus. Cameras with standard instead of "slip-ring" lens mounts would have to be either eye focused or recalibrated.
2. Adjusting lenses will necessitate "skimming" the ground glass back 0.0045 in.
3. Remove "stripper" shoe at back of main sprocket and replace with "cutaway" shoe.
4. Lock off clutch.
5. Substitute either a four-roller pressure plate, or a solid pressure plate. In the four-roller plate the top roller is straight while the other three rollers are crowned 0.003 in. The four-roller pressure plate is patented by the Cinecolor Corporation and license for use is granted by the patentees. The solid type plate is crowned 0.003 in. and is of polished chrome. Pressure can be obtained with a solid screw or by use of a spring twice the tension of the normal spring. In practice use is generally made of the solid screw for the four-roller plate, being careful to avoid "run-outs."

Boyle states that the proper adjustment of the pressure plate is very important; insufficient clearance with consequent "punching" will cause perforation damage and out-of-register images, while too much clearance will destroy contact of the rear negative resulting in "breathing" and out-of-focus pictures.

A test chart is photographed at the end of each day's work and the paired negatives carefully examined for contact, any lack of which is ruinous to the rear image. The back negative should be compared with a standard of excellence retained as a control.

Coated lenses have given the best results and satisfactory pictures have been made with lenses varying in foci from 24-40 mm., but such wide-angle lenses must be used with discretion.

Owing to the difficulty of obtaining adequate illumination with tungsten lighting and variations in colour temperature only the exterior type of bipack has been used in the Hal Roach Studios, in which a large number of two-colour films have been made. Generally H.I. arcs are employed, the general illumination being identical to Technicolor.

Boyle notes that back light should be kept to a minimum, only the necessary amount being used to give detail in hair and separate the colour planes. An undue amount gives bluish highlights. In exteriors, backlight causes grass and foliage to reproduce as brownish in hue and should be avoided. For street scenes and exteriors where there are no deep shadows, overcast weather conditions have given the best results

(H.I. arcs and booster lights assisting) for foregrounds and faces. The use of an ultra-violet absorbing filter helps in rendition of flesh colours and textures. In general the set should be fully lighted, avoiding deep shadows. With coated lenses at an aperture of $f/2.8$ a keylight of 500 foot candles is employed, filled to an over-all luminance of 650 foot candles. For night effects and somewhat deeper shadows, less fill and more cross-light should be used. Night effects are accentuated by the use of "practicals" and brightly lit windows. Generally some twenty per cent. of the lights used are tungsten lamps used with Macbeth "Whiterlite" filters. Occasionally ordinary incandescent spots are used without correction to emphasize reds or orange. Because of the volume of light necessary, large units are used as far away from subjects as set construction will permit. The familiar Y-I filter is used on all H.I. spots, to cut the excessive blue-violet, but as in Technicolor lighting, the Mole-Richardson broadsides are used without filters. The side arcs give a colour-temperature of $5,500^{\circ}$ K. The H.I. arcs with 170-Y-I Brigham gelatines are $5,900^{\circ}$ K.

Make-up should be on the light side to avoid a red-orange or sallow complexion. Lip rouge should be an orange-red. Grease has given better results than "pancake" and no make-up is used above No. 25. Owing to the light make-up, blended modelling is used to prevent masking appearance and to break up colour into planes. For men, a beard cover must be used, otherwise the beard will reproduce as a blue shadow. No make-up is used on children. Three-colour make-up has not been a success, indeed standard black-and-white make-up in lighter values has been found more suitable.

White shirts, towels and bedding should be dyed a buff otherwise the whites will be too "cold."

Fluorescent cloth has been successfully employed to obtain a colour of high saturation.

Very complete preliminary tests should be made to determine the precise reproduction (in advance) of all the principal costumes and furniture and interior decoration.

Instructions for adaptation of standard Bell and Howell camera for bipack. (By courtesy of Bell and Howell Company.)

When two films are to be run in the camera, as for the bipack colour process, or any other processes requiring such arrangement, it is essential to maintain perfect contact of the two film emulsions during exposure time, in addition to securing perfect registration of both films.

The Bell and Howell "Unit I" film mechanism, which is equipped with *stationary* pilot pins and full-fitting driving pins, is the most accurate intermittent movement available and ensures automatically perfect register even though difference in length, due to shrinkage, may be found in the film raw stocks.



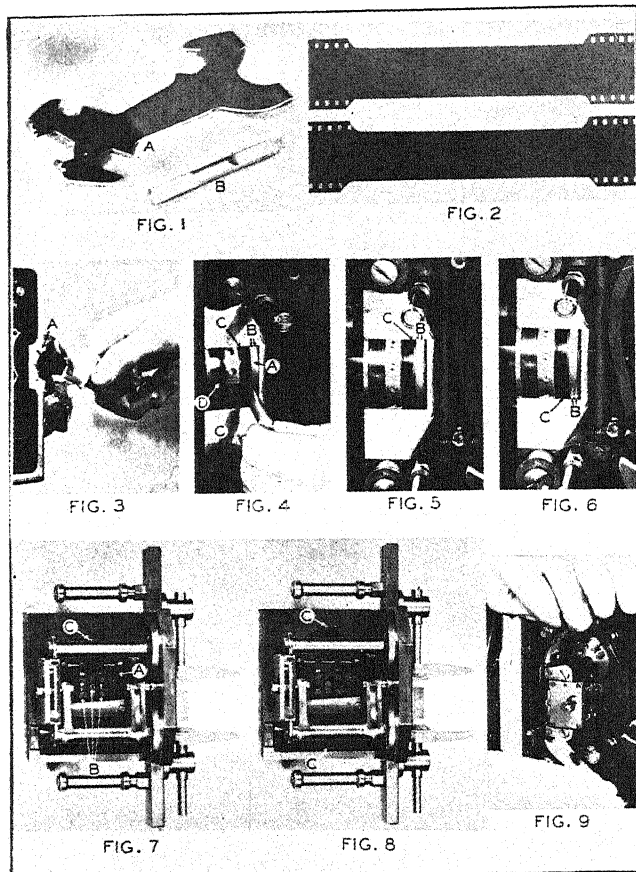


FIG. 302.

The Bell and Howell "Unit I" film intermittent mechanism is, furthermore, so designed that sufficient clearance exists between the film register leaves, which form the film channel, to eliminate all dangers of surface scratches and abrasions. During the periods of film motion, the film, or films, are free from frictional contacts and it is only during stationary periods of exposure that the film is accurately located at the focal plane of the photographic lens.

This control of film positioning is absolutely under control when *one* film is run into the camera, but air pockets may form between two films when they are simultaneously run through the mechanisms. These air pockets are due to the resistance of two relatively large surfaces to keep in absolute contact.

To eliminate the possibility of such occurrence, the Bell and Howell engineers have devised means to incorporate in the back register leaf a set of five rubber buttons which are made to protrude from the inner surface of the lead and act as air "squeegees" during the fleeting instant during which the film is *stationary* at the aperture and the camera shutter is not as yet in its cycle of exposure.

With due consideration to the above, it is quite obvious that the best solution to the problem of securing equally "sharp" images for black-and-white single film work and bipack, double film process, is to secure two interchangeable film intermittent mechanisms, one for black-and-white and one for bipack work.

The two mechanisms can be delivered so that they are interchangeable with absolute security. If a camera in the possession of the user is to be so adapted, it is necessary that it be sent complete to our works for careful installation of both mechanisms so that the films register perfectly at the focal plane.

If two film intermittent mechanisms—one for black-and-white and one for bipack—are available, there is no need of further concern, as they will be perfectly interchangeable. However, at times it will be found desirable to use only *one* "Unit I" film intermittent mechanism which is so constructed as to be readily converted for single or double films operation.

The following instructions contemplate such a case.

Instructions for using a single "Unit I" B. and H. intermittent mechanism, interchangeable for single or twin films

A. *Tools* (Fig. 302). Make sure that you have available the two wrenches which are delivered as standard equipment with each camera and which are illustrated in Fig. 302.

1. General utility wrench No. 231.
2. Front and rear ball bearing cone wrench No. 233.

Also prepare two strips of film about 6 inches long, cutting out the

film perforations over a length of approximately 3 inches, as shown in Fig. 2.

B. Withdraw the " Unit I " film intermittent mechanism and, using the general utility wrench, loosen the lock nut A (Fig. 3) at the rear of the camera, turning it slightly counter-clockwise as illustrated in Fig. 2.

C. The cam setting rim " A " (Fig. 4) is then loosened and can be set at will. If it is found that it is difficult to loosen it, use wrench " B " (Fig. 1) as illustrated in Fig. 4.

Do not force the turning of the ring and if it still offers resistance with the use of the wrench, merely tap the lock nut " A " (Fig. 3) with the heel of the palm of the hand to jar it loose.

Note that two reference dots " B " (Figs. 4, 5 and 6) are engraved on the rim of the cam setting ring which are to coincide with the edge of the casting " C " (Figs. 4, 5 and 6) and which by their positionings set the cam " D " so that it will bring the film mechanism register leaves, and therefore the film emulsion or emulsions, to the focal plane, with exacting precision.

D. When the two dots " B " (Fig. 5) coincide with the upper edge of casting " C " (Fig. 5), the intermittent film mechanism is set to bring the first *emulsion* at the lens focal plane for *bipack* (double film) operation.

When the two reference dots " B " (Fig. 6) are brought to coincide with the lower edge of the casting " C " (Fig. 6), the intermittent film mechanism is set to bring the film emulsion at the focal plane for " single film " operation.

E. After setting the cam ring at its proper position, lock the lock knob at the rear of the camera, using the general utility wrench, turning it clockwise as illustrated in Fig. 3.

F. You are ready now to insert in the camera the " Unit I " film intermittent mechanism. See to it that it is pushed fully home and it can be easily locked in place with the provided locking latches.

It is now possible to use the camera for either single film or double film work, according to the setting of the camera *in* and *out* register leaves cam.

G. The rear register leaf " A " (Fig. 7) is equipped with five rubber buttons " B " (Fig. 7) which can be pushed forward to protrude from the inner face of the back leaf, or retracted to be flush with this leaf surface by a combination of leaves and suitable springs.

When the levers " C " (Fig. 7) are in the position shown in Fig. 7, the rubber buttons are flush with the inner active face of the back register leaf and are in position for " single film " operation.

When the levers " C " (Fig. 8) are pulled out in the position shown in Fig. 8, the buttons protrude from the inner active face of the back register leaf and are in position for " double film " operation.

H. Although the setting of the camera cam is very easy and accurate

if the above instructions are followed, it is good practice to check the film tension after the final adjustment of the rubber buttons is made.

If the buttons are set for single film operation, take one single piece of film cut as shown in Fig. 2 and insert it in the "Unit I" film intermittent mechanism as the film would be threaded for photographing operation.

The fact that the portions of the film where the perforations are, are cut away, ensures that there will be no interference from either the pilot or the driving pins.

Using the small crank supplied as standard equipment with the camera at the rear single frame shaft, make sure that the register leaves are in such a position that they bring the film to the lens focal plane (photographic position).

Without disturbing this positioning, take hold of the film strip as shown in Fig. 9 and move it up and down in the film channel.

The film must be free to move without effort *but a slight resistance* (film tension) must be felt.

Experience, easily acquired, will tell when proper tension is applied.

I. If the buttons are set for double film operation, make the same film tension test, using, however, both strips of film instead of only one. Tension resistance must be felt in either the single or the double film test.

J. The double compartment, double set film magazines are to be loaded as illustrated in the general view of the camera.

It is important that the film loops be formed as illustrated, that is to say, the front film loops must be *one perforation longer* than those of the back film.

The driving and take-up sprocket film guides and the sprocket teeth are so designed and constructed that they take adequate care of either single or double film.

NOTE.—It is advisable to make the film tension test even when two "Unit I" film mechanisms—one for single and one for double film—are available. Film thicknesses may vary ever so slightly within accepted tolerances, or film tension adjustments may need checking. Precautionary measures will never be found useless for exact results.

K. After completing the film tension check, the camera is ready to be threaded with raw film.

For single film, the camera is, of course, threaded in the regular way, using the standard film magazines.

For double film operation, the coupled "bipack" magazines are used and the film threaded as shown in the general view of the camera.

It is important that the loops of the front film be of greater size (one perforation longer) than the loops of the second film.

The film magazines coupled for bipack work can be disassembled into two single units for individual use with single film. The lower

magazine is, however, equipped with a special adapter, and when used as a single magazine, the opening on top of the casting must be closed with the special cover plate supplied, and a longer fastening rod is to be used to attach the magazine to the camera.

L. From the above, it is quite evident that when using the interchangeable "Unit I" film mechanism for double films, the lens focal plane of the camera is *pushed back* an amount sufficient to compensate for the extra thickness of the front film.

Since the ground glass at the focusing aperture is precisely set for the focal plane of the emulsion of the single film, compensation must be devised for setting the lens so that it will properly focus at the displaced focal plane. To this effect an index marking is engraved on the lens holder, identified with the reference letter *B* (Bipack).

Focus visually the object through the regular ground glass and before operating the camera, rotate the lens mount so that the distance marking found by visual observation is switched to the "*B*" reference marking engraved in the lens mount.

For extremely close-up work such as titles, it is suggested that a photographic check of the "*B*" marking be made, and additional reference points be determined according to the particular requirements of the operator.

The above instructions are very easily followed, and all operations require only a few seconds if performed in their sequence and with normal care.

AGFA LENTICULAR BIPACK. (Not obtainable.)

By a very ingenious application of the lenticular film principle Agfa showed that it is possible to obtain three-colour negative separations from a single exposed frame of a bipack (E.P. 395,124). The front film of the bipack was a normal lenticular embossed base coated with an orthochromatic emulsion (*e.g.*, sensitive to green and blue light). The back film was similar to that of an ordinary bipack, namely, coated with a high-speed panchromatic emulsion. The emulsion on the front film was coated with a red filter to exclude all green and blue light from the back film. We had here a perfectly normal bipack of the standard Agfa type as far as emulsion coatings were concerned, but with the difference that the *front* film was a lenticular base. The front film was caused to bear two records by means of placing a banded filter on the lens in the usual position, that is, just in front of the lens. (For a description of the optical principles of lenticular film see "Lenticular Processes.") The banded filter in this case consisted of two colours, one yellow and one magenta, divided into three sections, magenta in the middle and a band of yellow on either side.

We know that a yellow filter transmits red and green and absorbs *blue*, and that a magenta filter transmits red and blue and absorbs *green*.

Thus red was transmitted by *both* filters, and besides red the yellow transmitted green and the magenta blue.

Therefore the front film, according to the optical principles of the lenticular process, and by virtue of its sensitivity to green and blue, bore a record of alternate juxtaposed stripes, or bands, representing in densities varying proportions of green and blue light and hence two of the primary records; whereas the back film bore a *continuous* image representing the record of red light.

After exposure the films were developed and reversed to positives, or developed as normal negatives if desired.

In order to print from either the green or blue record separately, it was necessary to print with coloured light, using a banded filter relatively in the same position as when the picture was exposed. The printing had to be done on a panchromatic emulsion. A banded filter was carefully mounted in a position exactly corresponding to that which it occupied in the camera, a normal step-by-step contact printing machine being used (preferably equipped with pilot pins for registration). For illumination a special single-filament lamp was employed, somewhat like a "strip" lamp, the filament being at right angles to the filter bands. The filament was therefore horizontal and formed a brilliant strip of light immediately behind the filters. By temporarily blocking out one or other band of the filter one could extract a direct negative record of one of the two banded images on the front film. The other part of the filter was then blocked out in its turn and the second record extracted.

Such a lenticular bipack was well suited for printing upon Gasparcolor three-colour positive film. For this purpose both original films were first reversed. By using blue filters for the two outer sections of the banded printing filter and a red filter for the middle band it was possible to print the magenta and yellow layers of the Gasparcolor film simultaneously. The yellow bands on the camera filter were responsible for the green records on the lenticular film. Replacing yellow by blue, one printed the magenta layer, which was sensitive to blue light only. Similarly the magenta filter was responsible for the blue record on the front film. Replacing this by red when printing, one printed the yellow layer of the Gasparcolor film which was sensitive to red light. Thus these two layers could be simultaneously printed each from its appropriate part of the double lenticular image. The back film with its continuous red record was afterwards used to print the other side of the Gasparcolor material which was coated with cyan dyed emulsion.

The dimensions recommended for the filter bands were different for various camera objectives. The following was an example:

COLOUR CINEMATOGRAPHY

ASTRO *F*/1·8 50-MM. FOCUS, TYPE III

<i>Height of Band.</i>					<i>Yellow Filter.</i>	<i>Magenta Filter.</i>
Daylight	..	..	..	..	10 mm.	25 mm.
Arc	..	..	..	..	25 „	25 „
<i>Width of band:</i>					7 mm.	7 mm.

For printing from negatives taken with the above lens:

Height of bands 25 mm.
 Width of bands 12 „
 The filter to be placed 83 mm. from the printing gate.
 The special horizontal strip-filament lamp to be used.

Lenticular bipack is capable of providing accurate three-colour separation, but prints derived from such records exhibit poor resolving power and do not stand comparison with the best of contemporary processes.

PART TWO

Nothing has such power to broaden the mind as the ability to investigate systematically and truly all that comes under the observation in life.

MARCUS AURELIUS.



Background or Process Projection

THE Process Projection Committee of the Society of Motion Picture Engineers in 1939 put forward a report embodying detailed recommendations for process projection equipment. For this information the technical reader is referred to the original report (1). Here only those aspects of process projection will be considered which arise in the technique of colour films.

Process projection, called in Britain "background projection," a somewhat more precise description, assumed great importance economically in ratio to the continuous rise in the cost of film production. But whereas weather conditions are reasonably reliable in California, they are notoriously unreliable in Europe, and particularly so in Britain; and since process projection, as a technique, was evolved for the purpose of dispensing with the necessity of location photography, one would have expected the technology to have reached an even more advanced stage in Britain than in Hollywood. This does not seem to have been the case, however, and it must be acknowledged that the optical projection apparatus developed in America is far superior in every way to that with which most British studios have hitherto been equipped. This need not have been so had not the promoters of studios been more interested in the "rackets" they were working than in the equipment they made available to the sincere technicians they employed. It need not have been the case, because it would have been a simple matter for any competent studio owner at any time in the last ten years to have formed a committee of British manufacturers who, between them, could have devised apparatus in every way equal to the American machines. But the interest of those who were in the position to spend money on equipment did not lie in the welfare of the industry, even as a means for increasing their profits; they were concerned alone in persuading the British public to subscribe as quickly as possible the maximum sum and then retiring from the business with a title and a fortune collected between two picture booms.

It was soon found in America that the enormous cost of making location shots in Technicolor could be avoided only by the maximum possible use of process projection. And the most effective mother of technical invention is necessity in the form of dollars.

Compound triple-head projection was the answer to the problem,

and such a multiple process projector was first constructed by those hardy pioneers Warner Brothers, who received the Academy Award in 1938 "for pioneering the development and for the first practical application to motion pictures of a triple-head background projector." Byron Haskin, of Warner Brothers' Studios, describes how this conception originated in the special needs of the Technicolor picture "Gold is Where You Find It," in which occurred a sequence of the flooding of a valley, which could only be shot by a combination of process projection and miniature backgrounds. At that time colour process shots were limited to a 9 ft. \times 12 ft. screen, and the foreground settings, consisting of flumes, hydraulic guns, and numerous shacks, were too large in scale to be combined with such a small screen. The job was impossible with a single projector. Since it was known that the maximum light delivery of which the single projector was capable had been reached, "the thought occurred that, provided additional projections could be superimposed over the one to compose a single image, the brilliancy of the picture should be compound respectively and, by ratio, expand to the size required. After discussion relative to the amount of light needed we determined to attempt to superimpose three projectors (*sic*) because, in theory, this compounding of light would be enough." Many difficulties had to be surmounted. The parallax which would have resulted from the toeing-in of three projectors mounted side by side was avoided by mounting two projectors on each side at right angles to a central one and using 4-in. prisms to reflect the side beams at such an angle as to register perfectly upon the screen (*viz.*, slightly more than 45°). Subsequently, fused quartz optically polished flats with aluminized first surface were substituted for the prisms.

In the Warner process projector the optical part of the projection system is rigidly fixed to a metal base forming an optical bench assembly; and for the purpose of focusing, the lamp housings and projection movements are bodily moved back and forth on dovetailed ways. Sets of mounts are dowelled to accept matched sets of lenses which are "always the same focal distance from the screen, eliminating the necessity for superimposition when changing the size of the picture." The "gun-mount" base swings laterally around an axis equidistant from the three lenses and rotates vertically about the axis of the two "outboard" lenses, thus never altering the focal distance of any of the lenses from the screen during the positioning of the picture (2).

Farciot Edouart of Paramount describes a similar instrument (3). Paramount at first made the very interesting experiment of using the projector for three-colour additive projection, employing the appropriate black-and-white plates or films projected through the standard tricolour filters. The loss of light was, however, excessive, as will be obvious if we consider the very low efficiency of the blue filter to which

BACKGROUND OR PROCESS PROJECTION

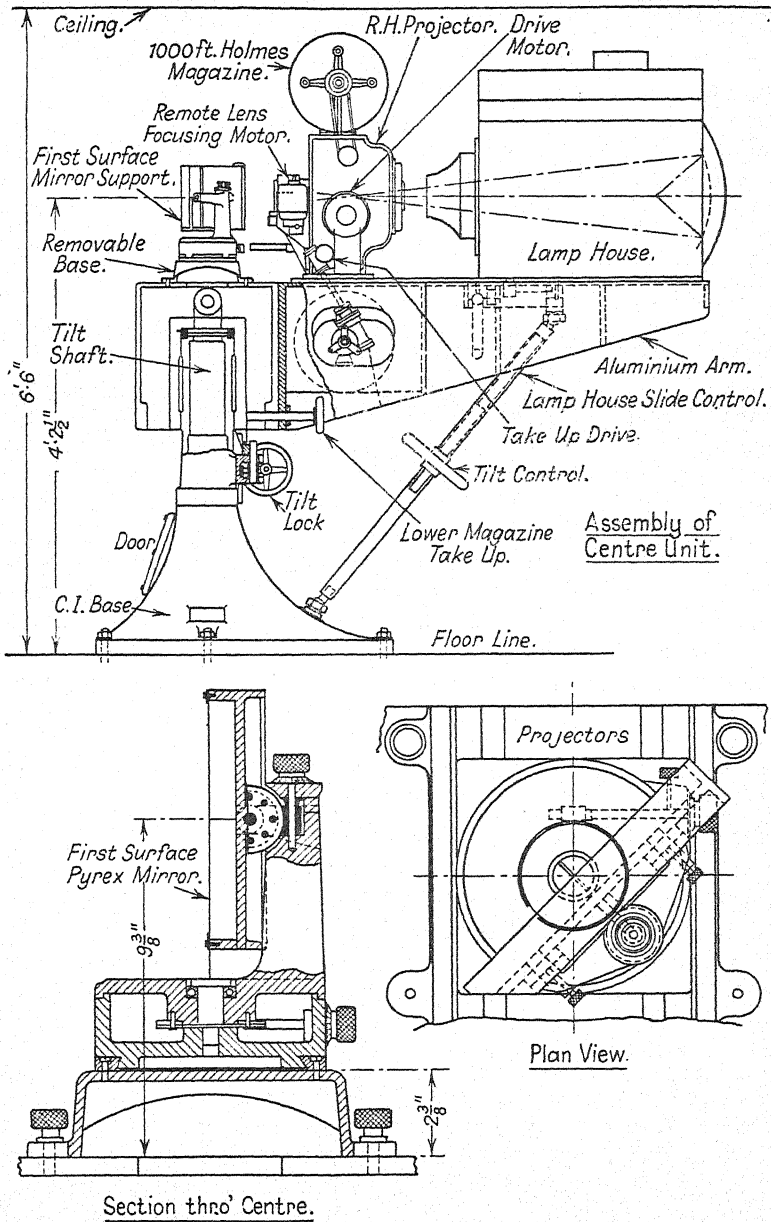


FIG. 303.—Paramount Triple-head Projector. (Courtesy of Paramount Pictures, Inc.)

the other two would have had to be balanced. Probably there was nothing gained as compared with projection by the single instrument using a complete subtractive transparency. This method was quickly abandoned in favour of three identical Technicolor prints projected in superimposition and perfectly registered on the screen.

The Paramount unit, like the Warner one, consists essentially of three standard transparency projection units, each with its own lamp-house, film movement, and optical system mounted on a common base, and the whole erected in a sound-proof booth which may be on castors, or else, in turn, firmly mounted on a concrete base (Fig. 303).

The central projector is placed parallel to the axis of projection. The other two are mounted at right angles to the axis of projection, facing inward towards that axis. The two beams from the side projectors are reflected by first surface aluminized mirrors at an angle of slightly more than 45° . The three film movements are driven in synchronism with the camera by electrically interlocked synchronized motors. There is provided remote focusing control from the camera position. The central image is at first focused and lined up; afterwards the side images are matched to it in registration and focus. This does not seem to have been as convenient an arrangement as on the Warner instrument, and it is probable that it has since been modified. It is said that the two side images took from three to seven minutes to register to the central one.

Farciot Edouart reported that the increase in screen luminance was no less than 280 per cent. more than was possible with the single projector.

It is evident that for the purposes of colour photography the following conditions must be met:

- A. There must be the minimum fluctuation of luminance and distribution of energy in the light-source.
- B. The colour-temperature of the source must be a match to that of the illumination of the foreground.
- C. There must be accurate control of the total of the light emitted, in order to be able to adjust the ratio of the photometric value of the foreground to that of the background. This is at the discretion of the camera operator.

Requirement A has been met by choosing types and sizes of carbon for the superlatively high-intensity arcs used, as recommended by the manufacturers to give maximum efficiency, and controlling burning conditions so as to provide minimum flutter. The screen luminance variation should be less than ± 2 per cent. per minute, but with a maximum of 5 per cent. for any consecutive nine-minute shooting period. It is laid down that the minimum output of an F1/6 relay type condenser system should be 25,000 lumens.

Requirement B has been met by providing that the carbons be burned at within ± 5 amperes of their rate current.

Requirement C has been met by the use of a heat-resisting diaphragm light control which is placed at a suitable point in the relay condenser system. With such a diaphragm the light output is easily controlled while retaining even distribution.

It is recommended that a separate power supply be provided for the light-sources, inasmuch as a constant line voltage to the arcs is imperative in order to meet the conditions above described.

References

- (1) Society of Motion Picture Engineers, Report of the Process Projection Committee, *Journ. Soc. Mot. Pic. Eng.*, **32** (1939), pp. 589-609.
- (2) HASKIN, B., "The Development and Practical Application of the Triple-Head Background Projector," *Journ. Soc. Mot. Pic. Eng.*, **34** (March 1940) p. 252.
- (3) EDOUART, F., "Paramount Triple-Head Transparency Process Projector," *Journ. Soc. Mot. Pic. Eng.*, **33** (August 1939), p. 170.
"The Paramount Transparency Process Projection Equipment," *Journ. Soc. Mot. Pic. Eng.*, **40** (June 1943), p. 366.
- (4) EDOUART, F., "High-Efficiency Stereopticon Projector for Color Background Shots," *Journ. Soc. Mot. Pic. Eng.*, **43** (August 1944), p. 97.

Colour Film Sound Tracks

THE advent of the sound film did not offer an obstacle to the Technicolor laboratories because it had always been their practice to include a key silver print on top of which the dyes were imbibed even in the days of two-colour Technicolor. Today Technicolor use the silver print generally for the frame-surround and do not include a key silver print in the image area. From the earliest days of sound the Technicolor track was normal. Indeed, some claims were made as to an inherent superiority owing to the opportunity to develop the key positive bearing the track to ideal gamma without making any sacrifice to picture quality, the making of which was completely independent of the positive development stage. This may have been particularly true of variable density track.

Two-colour processes other than the earlier Technicolor, such as Cinecolor and Multicolor, employed, however, double-coated film stock the respective sides of which were toned generally by inorganic agents to red-orange and green-blue. The final image was therefore coloured, although often of considerable opacity. The troubles which were experienced were first described by R. M. Otis of Multicolor in 1931 [1]. He remarks: "The sound track is printed in blue. In variable density recording the blue track differs from the black-and-white track in the increased contrast of the blue over the black track before toning. The blue track is developed to a gamma of 0.5. The essential property of a good sound track is that there should exist a linear relation between the transmission of the positive as viewed by a photoelectric cell and the exposure of the negative. Fig. 304 shows this relation for the Multicolor blue track as seen by the caesium and potassium photoelectric cells." Otis observed that modulation of a blue track was best rendered by a photocell sensitive mainly to red, such as the caesium cell, since to this cell the blue track would be as opaque as black. The infra-red transmittance of ferric ferri-cyanide blue-toned silver would not be excessive, since this compound has low infra-red transmittance.

The dilemma was faced at about the same time prior to the war in England by Dr. Bela Gaspar, because in his process for the first time the final image was a pure dye image, and since his positive film was coated on both sides he could have had a dye image track in blue on white or

red on white. The red track was fairly satisfactory with potassium oxide photocells, but useless with caesium photocells. Similarly, the blue track was useless with caesium cells owing to excessive transmittance of deep red. It was therefore essential to use a silver track with a two-layer background of red (yellow minus magenta). As this was a reversal bleach-out process, it follows that a silver and white track was impossible, as the developed silver was necessary to destroy the dye in the layers. The procedure adopted was as follows:

1. The track was printed on the yellow-magenta side. (See Gaspar-color.)
2. The opposite cyan side was fogged on the track area.

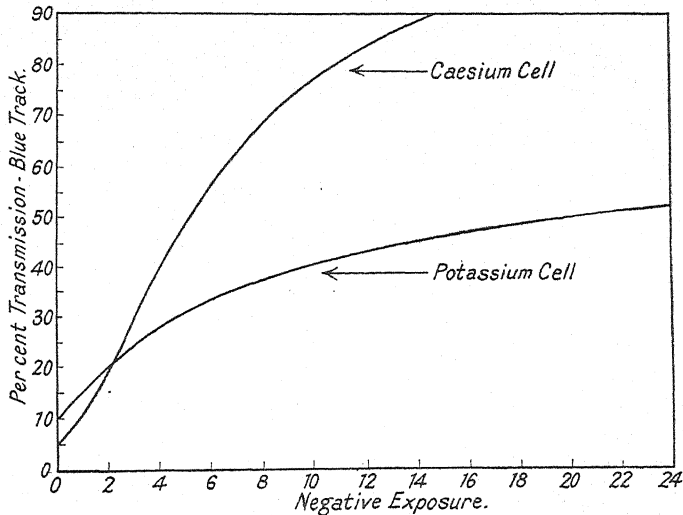


FIG. 304.

3. Fixed. Silver was here eliminated in the unmodulated area.
4. Dye-destroyed in area where developed silver was present.
5. The developed silver track, in common with the picture area, was converted to silver chloride in preparation for elimination of all silver in the picture area.
6. The sound track was locally redeveloped before reducing the silver chloride in the picture area.
7. Fixed and washed.

The outcome of this procedure is an opaque silver image on a red unmodulated background. This track met the conditions imposed by the region of sensitivity of caesium oxide photocells because the transmittance of the red background was nearly as efficient as clear film for the radiation to which the cell was sensitive. The apparatus

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for redeveloping the silver chloride sound track consisted of a coating wheel about $1\frac{1}{2}$ inches in diameter, its coating edge being concave with reference to the film. This concave edge dipped into a small coating trough filled with a viscous solution of developer and a meniscus was formed with the film surface. The boundary of the redeveloped track was unexpectedly straight and little or no trouble was experienced with development running into the picture area. However, in a laboratory this is a delicate and rather messy operation which necessitates skilled and continuous attention.

The Gasparcolor sound track redeveloper formula was as follows:

Metol	..	..	..	..	10 gm.
Sodium sulphite (anhyd.)	..	..	..	..	120 "
Hydroquinone	..	..	..	..	30 "
Sod. hydroxide	..	..	..	..	50 c.c. (40% solution)
"Nekal"	..	..	..	..	10 "
Dextrin	..	..	..	..	200 gm.
Water	..	..	..	..	400 c.c.
Time 3 minutes.					

NOTE.—"Nekal" is an I.G. Farben trade name for the wetting agent referred to in Agfacolor formulæ as S.55. The agent is sodium alkyl naphthalene sulphonate. ($C_4H_9-SO_3Na$.)

The boundary of the area of action of this edge development has to be confined to a zone only 0.015 in. wide between the track and the picture, and the action of the fluid must be absolutely uniform across the zone of application with no variation in the vicinity of the sprocket holes; and agitation as a means of securing uniformity is obviously excluded [5].

When Agfacolor 35-mm. Negative-Positive was released for feature pictures rather prematurely in 1941 by order of Goebbels and his henchmen it was decided to use a silver sound track, and the only way of doing this was to restrict the silver bleach (prior to elimination of silver from the film) to the picture area, and the method adopted was to coat by means of a roller the picture area only with a bleach sufficiently viscous to prevent its overlapping the sound track. This was exactly the opposite to the Gasparcolor technique, because the process of colour formation was also the opposite. The formula for this viscous bleach was:

Oxymethyl cellulose. Trade name Color-	..	..	..	60 g.m.
coll), also known as "Tylose"	..	..	..	100 "
Potassium ferricyanide	..	..	..	1,000 c.c.
Water	..	..	..	..
Time: 3-5 minutes.				

Monopack films being, as a rule, coated on one side of the film base only, it is obvious that it is easy to print the sound track as a pure dye image if the whole surface of the film is permitted to pass through all stages of the processing. The transmittance of the Agfacolor "black," which is constituted by full density of colour formation

in all three layers, is visually a dark bluish grey. In good samples it is surprisingly neutral. As will later be remarked, some advantages are to be obtained by printing a *two-layer* track in which the modulation is confined to an image given by the yellow and magenta layers only.

In Germany it was soon realized that the existing photosurface of caesium-silver-oxygen in the standard photocells would be very

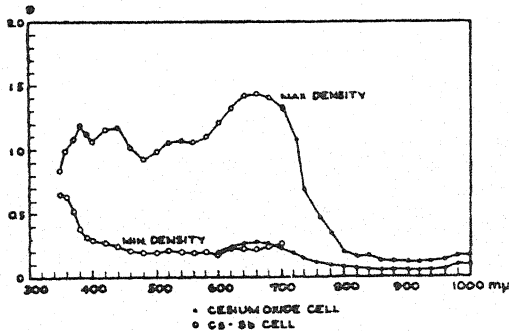


FIG. 305.—Density of Agfacolor sound track as a function of wavelength (R. Gorisch and P. Görlich).

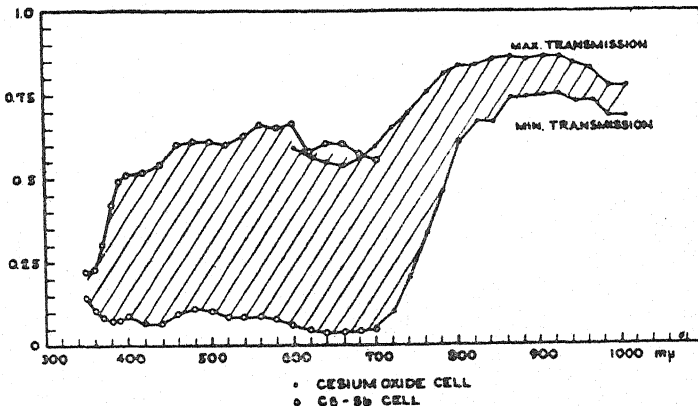


FIG. 306.—Transmission of Agfacolor sound track and fog as a function of wavelength (R. Gorisch and P. Görlich).

inefficient owing to the maximum sensitivity in the infra-red,¹ the very region in which the dyes formed in monopack processes have high transmittance; there is therefore a narrow modulation range. Gorisch and Görlich [2] point out that, "If we multiply for each wavelength the three factors influencing the magnitude of the photoelectric current, that is, film transmission, sensitivity of the cell, and sound lamp radiation, as is done in Fig. 305, we obtain the spectral distribution of the product of these cells as shown by the curves of

COLOUR CINEMATOGRAPHY

Fig. 306, represented by the designation caesium oxide cell. The two cases of maximum and minimum density are shown. The area lying between such a curve and the abscissa corresponds to the total current flowing through the photoelectric cell. The area between the average

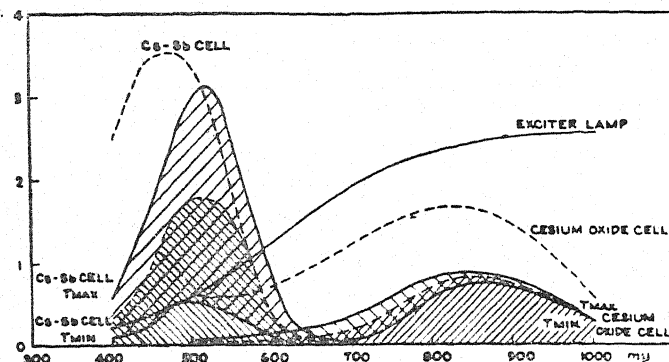


FIG. 307.—Relationship between photocell current and wavelength for Agfacolor sound track and 2 photocells of a different type. The spectral sensitivity curves of the 2 photocells as reduced to equal energy input and the spectral characteristics of the exciter lamp are also shown (R. Görlich and P. Görlich).

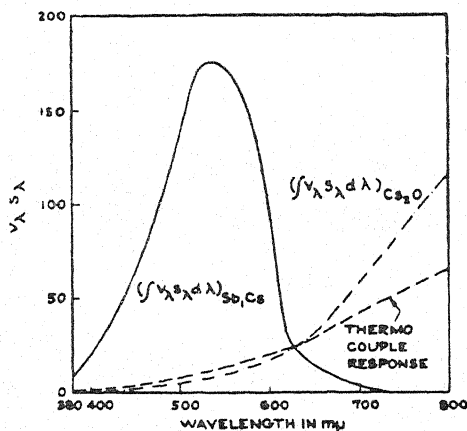


FIG. 308.—Relative spectral response of caesium oxide and Cs-Sb photoelectric cells (R. Görlich and P. Görlich).

of the two curves and the abscissa represents, therefore, the average photocell current, the area between the two curves the photocell modulation. For the caesium oxide cell we cannot expect good results on account of the poor relation between the two areas" (Fig. 307).

The answer to this problem was found in the characteristics of the caesium-antimony alloy cathode (Fig. 308).

In the United States in 1944, Dr. A. M. Glover of R.C.A. was approached by J. A. Ball of Du Pont, who was chairman of the S.P.M.E. Color Committee, to learn whether a phototube could be provided having the same spectral characteristics as the R.C.A. 929, but with high sensitivity, so that it could be substituted for the 868 caesium phototubes in existing reproducing systems without the necessity of providing additional amplifier gain. The 929 phototube has its maximum sensitivity in the visible spectrum and has no response

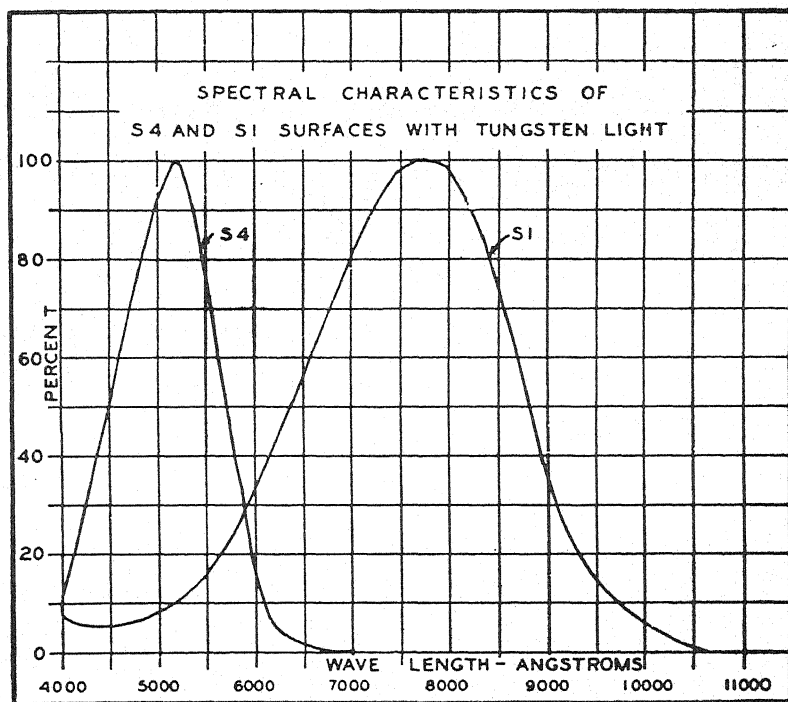


FIG. 309.—Phototube characteristics of S1 surface used in RCA Type 868 and S4 surface used in RCA Type 929 and IP 37 (R. O. Drew and S. W. Johnson).
(Courtesy of R.C.A.—U.S.A.)

to infra-red light. Independently, the problem was presented to Dr. Glover by M. H. Sweet of Ansco. A new tube with similar cathode surface to 929 and with identical spectral characteristic, but with gas multiplication of the electron current, has been developed. This is designated tube 1P37. The photosurface of the old tube is designated S1 and that of the new tube S4 (Fig. 309).

The new R.C.A. 1P37 phototube fulfils the requirements of dye-image sound track. Its maximum sensitivity is in the short wavelength part of the visible spectrum between 4,000 and 4,500 Å. With a tungsten

filament source, the product of the spectral response curve of the tube and a light-source operating at 2,879°K. has a maximum response at 4,700 Å. Owing to its predominantly blue sensitivity, it is somewhat more sensitive to variation in the temperature of the source than the old photosurface [3].

Tests were carried out by R. O. Drew and S. W. Johnson [4] of R.C.A. on Ansco duplicating positive (Fig. 310) (see Ansco section, page 394). Four laboratory tests were made; these were—volume level, high frequency response, cross modulation, and noise measurement. The usual volume level test is to measure the output of a 1,000-cycle tone with full track modulation. Fig. 311 shows the output from dye

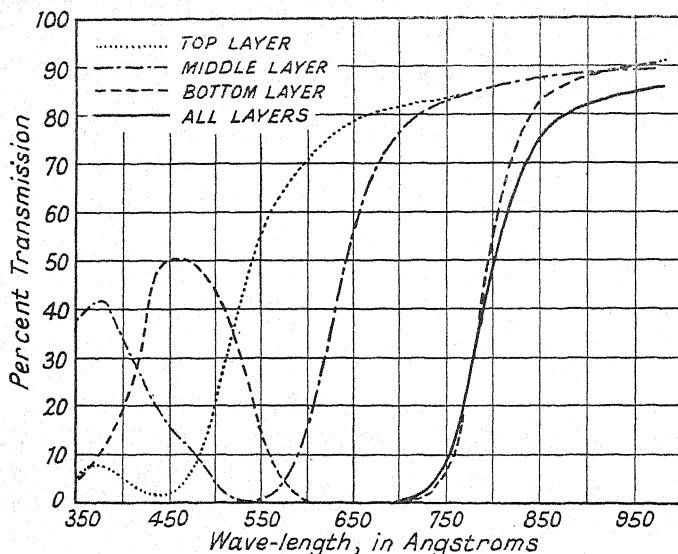


FIG. 310.—Dye characteristics of Ansco Type 132 duplicating color film (R. O. Drew and S. W. Johnson).

tracks made in several ways. The 1,000-cycle output from a silver track is taken as the reference or zero-db. level. Noise determinations consist in measuring the random noise output from an unmodulated biased track and comparing the reading with the 1,000-cycle full modulation output. The unmodulated biased track consists of two clear strips 0.003 in. wide with the remainder of the scanned area opaque. Film noise is caused by any photographic irregularities or graininess which may be present, and by scratches and specks of dirt. Such dirt specks as appear over the narrow clear areas produce fairly loud noises. Dirt in other areas causes noise in proportion to the light transmitted, so that low densities mean noisy films. The ratio of signal to noise, or relative noise level, is not greatly affected by some light

absorption in the clear areas, since this reduces intensities of both signal and noise. Low densities in the dark areas, on the other hand, raise the absolute magnitude of the noise and at the same time reduce that of the signal, and are therefore doubly injurious.

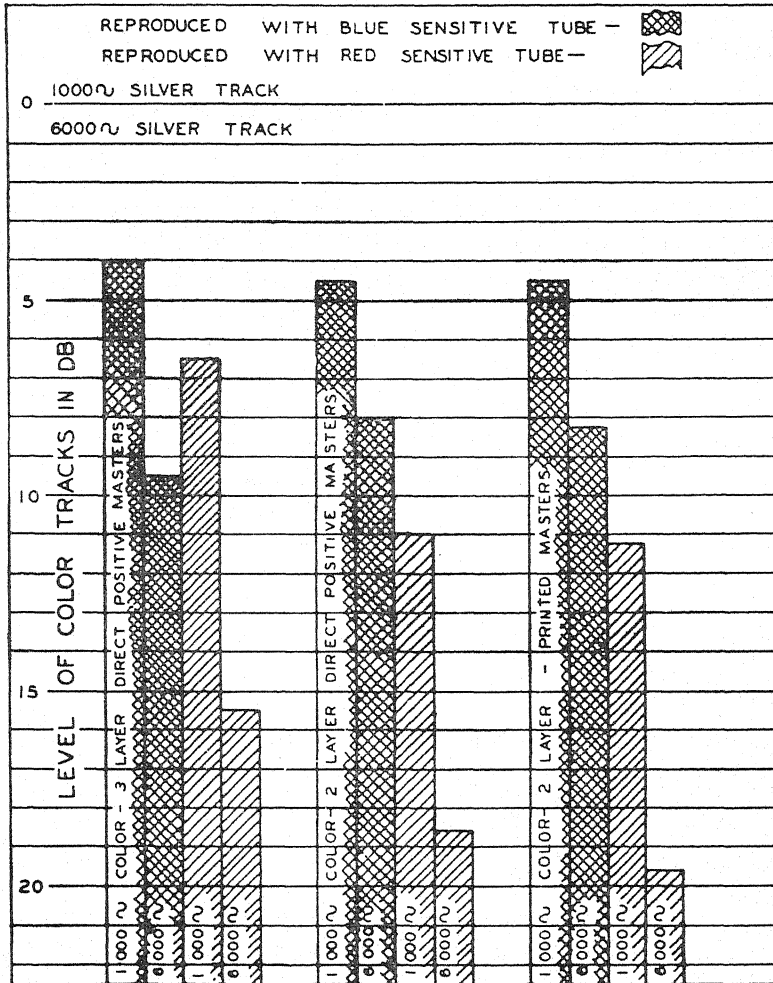
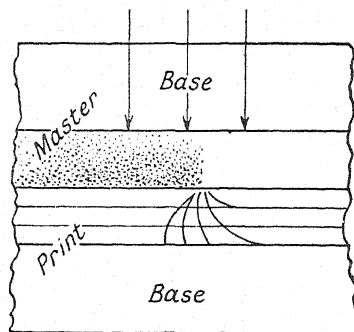


FIG. 311.—Relative output of colour tracks (R. O. Drew and S. W. Johnson from *Journ. S.M.P.E.*, May 1946).

Drew and Johnson note that the high-frequency loss and the cross-modulation are the result of diffusion of light within the emulsion which causes the exposure to spread outside the boundaries of the area where exposure is desired. This is especially so in the lower layers

of the emulsion (Fig. 312). Exposure by ultra-violet light helps to keep the image at the surface in recording and printing the usual silver tracks; and as is well known in high-contrast negatives and positive prints exposed to give high densities, the spread of exposure results in outward shifting of the boundaries, or "image spread." Image spread in a negative is cancelled by image spread in a print, and negative and positive densities are chosen with this object. For this balance the cross-modulation recording is a delicate test, and conditions that give minimum cross-modulation provide the best sounding prints. Satisfactory cross-modulation is 30 db. below signal.

Since the present motion picture Ansco stock is of the reversal type, the effect of diffusion of light in the emulsion is to eat into the area which should be opaque and cause image contraction instead of image spread. To neutralize this the black area of the master has to



Diffusion of Light in Print

FIG. 312.

be over-size, thus protecting a slightly larger area than that which is to be cleared of dye. Cross-modulation plots reveal similar V curves to normal negative-positive prints, but the distortions on opposite sides of the minimum point are of opposite sign. Thus, if the abscissæ are master (or negative) density, the branch of the curve to the right of minimum means undersize opaque image in the case of reversal prints.

Reversal printing involves the further problem of keeping the transparent areas clear, and this calls for complete exposure of the emulsions. On the other hand, since all the density obtainable is wanted in the dark areas, this part of the track must be almost completely protected from exposure.

Drew and Johnson say that the ideal printing master is a direct recorded positive [4].

As in silver prints best high-frequency response and density tolerances for good cross-modulation cancellation had been obtained by confining the exposure as near the surface as possible, endeavours

were made to accomplish a similar result by clearing the bottom layer by a fogging exposure to red light, leaving a two-layer (yellow-magenta) modulation (Fig. 313). The improvement is not marked. The diffusion of light under the edges of the black area extends farthest in the bottom layer, thus shading off the edges of the image; but since this takes place principally in the cyan-dyed layer, and the cyan dye transmits the green and blue light to which the 1P37 tube is most sensitive, the presence or absence of some of the cyan dye makes comparatively little difference in the phototube current. Such difference as it does make results from the fact that the cyan dye is not 100 per cent. transparent in this range.

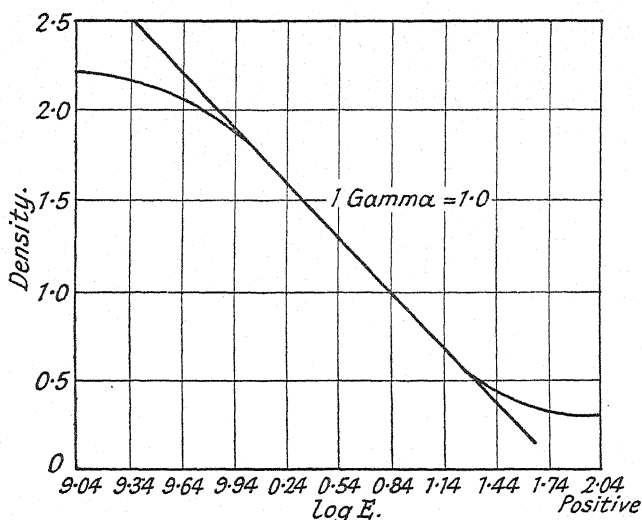


FIG. 313.—Sensitometric curves for type 11b sensitometric exposure of 2 layers of Ansco reversible Type 132 duplicating colour film. Densities were measured on micro-densitometer with tungsten light for the blue-sensitive phototube (R. O. Drew and S. W. Johnson, *Journ. Soc. Mot. Pic. Eng.*, May 1946).

Single-layer tracks (yellow), consisting of the top layer only, were no good because the tube is sensitive to green.

White light prints give a track which is somewhat blue in transmittance, and tests were made with a yellow filter in the printing light. Three thicknesses of Ansco No. 25 filter were used for printing three-layer tracks and one thickness for two-layer (Fig. 314).

Satisfactory cross-modulation cancellation for two-layer tracks printed from either a direct positive or a printed master was obtained. The 6,000-cycle output is only 3.5 db. below the 1,000-cycle output. Filtered printing light gives cancellation at lower densities than does white light and slightly increased density tolerance for 30-db. cancellation. Also, direct-positive masters recorded on the fine-grain, low-spread

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E.K. 1372 give slightly more 6,000-cycle output, and greater density tolerance for 30-db. cancellation than is given by masters recorded on the somewhat coarser-grained E.K. 1357. The three-layer tracks give

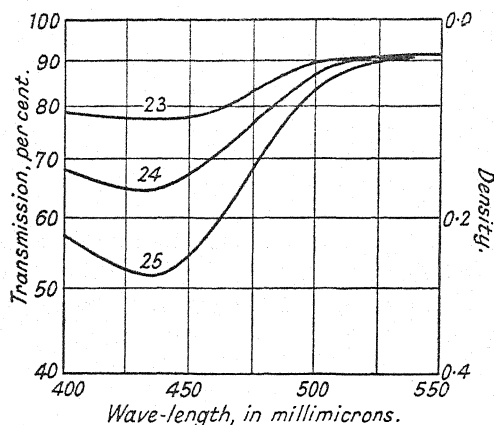


FIG. 314.—Spectrophotometric transmission curves for Ansco yellow series filters Nos. 23, 24, 25 (R. O. Drew and S. W. Johnson, from *Journ. S.M.P.E.*, May 1946).

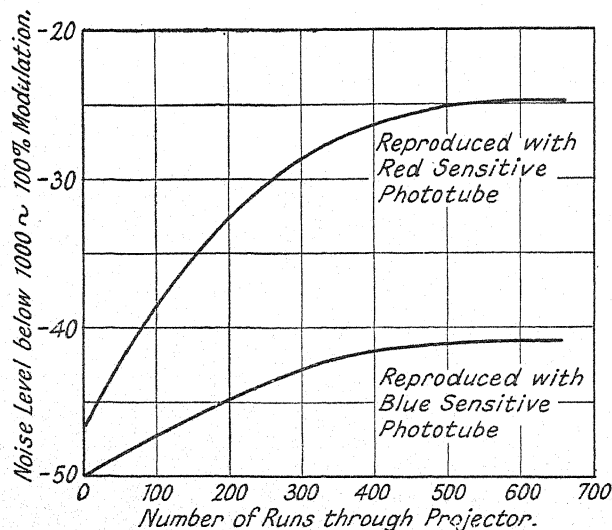


FIG. 315.—Curves showing relation between signal to noise for 3-layer biased unmodulated track and number of runs through a theatre-type projector (R. O. Drew and S. W. Johnson).

about 1.5 db. less 6,000-cycle response than the two-layer tracks. Both give about the same 1,000-cycle response, which is 4 db. below that of a silver track.

Fig. 315 shows the comparison of a three-layer track used with the 598

red-sensitive 868 tube and with the blue-sensitive 1P37. Using the three-layer track, the 868 tube is still at a disadvantage, not only in the transparency of the dyes to the infra-red light, which produces most of the phototube current of the 868 tube, but also in the arrangement of the layers, which puts the cyan dye layer at the bottom, or farthest from the surface where the printing light is applied, and hence where it gets the poorest printing conditions.

It is therefore assumed that good high-frequency response and low distortion are obtainable with dye tracks used with the 1P37 phototubes, with levels slightly below those from silver tracks, and with practically the same signal-to-noise ratios. Two-layer tracks have a somewhat superior performance as compared with three-layer tracks. Good tracks can be made from either direct positives or printed masters, provided a good negative is available for making the master. Masters should have higher density and more image spread for printing colour tracks than for making standard silver tracks, and the control for minimum distortion follows the usual cross-modulation test practice.

The above material is derived from the paper by R. O. Drew and S. W. Johnson (4), and the writer acknowledges his indebtedness to the R.C.A. Victor Division, the Radio Corporation of America.

Sound Trade Patents. Selected List.

E.P. 467,614	..	..	..	..	..	Eastman Kodak
E.P. 476,672	..	..	..	..	..	I.G.
E.P. 487,769	..	..	..	..	..	I.G.
E.P. 488,108	..	..	..	..	..	Eastman Kodak
E.P. 483,271	..	..	..	..	..	I.G.
E.P. 492,711	..	..	..	..	..	Gaspar
E.P. 494,144	..	..	..	..	..	I.G.
E.P. 503,940	..	..	..	..	..	Eastman Kodak
E.P. 505,214	..	..	..	..	..	I.G.
E.P. 506,514	..	..	..	..	..	I.G.
E.P. 516,536	..	..	..	..	..	Eastman Kodak
E.P. 518,612	..	..	..	..	..	Gaspar
E.P. 520,173	Eastman Kodak
E.P. 524,114	Eastman Kodak
E.P. 556,631	Technicolor

References

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- (2) GORISCH, R., and GÖRLICH, P., "Reproduction of Colour Film Sound Records," *Journ. Soc. Mot. Pic. Eng.*, **43**, 3 (Sept. 1944), p. 20. Translated from *Kinotechnik*, **24** (April 1942), pp. 43-6.
- (3) GLOVER, A. M., and MOORE, A. R., "A Phototube for Dye Image Sound Track," *Journ. Soc. Mot. Pic. Eng.*, **46**, No. 5, (May 1946), p. 379.
- (4) DREW, R. O., and JOHNSON, S. W., "Preliminary Sound-Recording Tests with Variable-Area Dye Tracks," *Journ. Soc. Mot. Pic. Eng.*, **46**, No. 5, (May 1946), p. 387.
- (5) Report of the S.M.P.E. Committee on Color, *Journ. Soc. Mot. Pic. Eng.*, **45**, No. 6 (Dec. 1945), p. 398.

Definition

The conversion of the metallic silver constituting the photographic image to a compound capable of selective absorption of light and therefore more or less strongly coloured. Alternatively the substitution of metallic silver by a coloured compound.

1. Metallic Toning

- (a) The metallic silver may be converted, for example, to silver sulphide, as in sepia toning.
- (b) The metallic silver may be substituted by a compound such as ferrocyanide. Ferric and uranium toning have been most frequently employed, the former giving an excellent cyan (ferriferrocyanide) and the latter yielding a reddish orange (uranium ferrocyanide). Murexide gives an unstable magenta.

2. Dye Toning

- (a) Silver iodide or uranium ferrocyanide are both strong mordants for basic dyes, and the conversion of metallic silver to these salts is a simple procedure.¹ Chromium has also been used. Copper ferrocyanide was patented by Traube in 1916.

3. Colour Development

- (a) Colour development, the oxidation products of which are insoluble dyes which are precipitated together with the silver developed image. Examples are leuco indigo and leuco thio indigo.
- (b) Colour coupling by development in which the oxidation products couple with a compound either present in the developer or dispersed in the emulsion to form an insoluble dye. Such dyes are generally of the indophenol or indamine class.

Differential Hardening of Gelatine

- (a) A silver image can be hardened by the action of a bleach and thereby provide a coloured image by the selective action of dyes for hardened or unhardened gelatine. Other methods

¹ See E.P. 547,722 for a new procedure for dye toning (A. G. Tull).

effect the converse, namely, soften the gelatine in the neighbourhood of the silver image.

- (b) Bichromated colloids, such as gelatine, can also be employed, differential hardening being produced by the action of light. The difficulty with this method is the requirement for long exposure to ultra-violet light.

TONING FORMULÆ

METALLIC TONING FOR TWO-COLOUR POSITIVE FILM (EMULSION-COATED ON BOTH SIDES OF FILM BASE)

By Courtesy of Dufay-Chromex Limited, London, England.

Processing Procedure

<i>Step</i>	<i>Description.</i>	<i>Time Minutes.</i>
1	Wash and surface wipe	4
2	Blue Toning (one side)	2½
3	Wash	8
4	Clearing Bath	1
5	Uranium Toning (Red-Orange)	5
6	Wash	5
7	Fixation	1
8	Wash	8
9	Ammonia Treatment	1
10	Wash	1
Total		36½

Blue Toner

Solution A.

Ammonium persulphate	50 gm.
Ferric alum	125 „
Water	2 litres

Solution B.

Oxalic acid	150 gm.
Water	2 litres

Solution C.

Potassium ferricyanide	100 gm.
Water	2 litres

Solution D.

Ammonium alum	200 gm.
Water	2 litres

Applied to one side of the film by flotation method. For use: Take

A	1 part
B	2 parts
C	1 part
D	2½ parts

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Dilute with equal quantity of water. Add hydrochloric acid, 10 c.c. per 500 c.c. of toner. Time of application, approximately $2\frac{1}{2}$ minutes.

Clearing Bath (Preliminary to application of uranium toner to increase transparency)

Hydrochloric acid	..	..	..	..	..	33 c.c.
Potassium oxalate	..	..	..	..	..	12 gm.
Water ..	..	..	..	..	..	1 litre

Time: 1 minute.

Important: The film is totally immersed from this stage onward.

Uranium Toner

Potassium oxalate	..	..	..	..	..	12 gm.
Uranium nitrate	..	..	..	..	..	10.5 ..
Hydrochloric acid (conc.)	..	..	..	..	..	32 ..
Potassium ferricyanide	..	..	..	..	..	9 ..
Water ..	..	..	..	..	..	1 litre

Time: 5 minutes.

Fixation

Sodium thiosulphate	..	..	..	..	..	200 gm.
Water ..	..	..	..	..	..	1 litre

Ammonia Rinse

Ammonia ('880)	..	..	..	..	..	1 c.c.
Water ..	..	..	..	..	..	1 litre

The function of this alkaline rinse is to modify the ferric blue to a line which is closer to the complementary of the uranium red-orange, thus providing better greys.

Remarks

The above formulæ will give images of remarkable transparency. The surface application of the blue toner can be done in a number of ways, one successful method being to draw the film forward horizontally while in contact with a number of $\frac{1}{4}$ " diameter glass rods, the level of the solution being kept roughly $\frac{1}{2}$ mm. below the surface of the rods. A meniscus is formed by capillary attraction *between* the rods and no solution creeps through the perforations. The sound track is generally printed on the blue side. The ferriferrocyanide image giving satisfactory reproduction with cæsium-silver-oxygen photocells (red sensitive).

YELLOW DYE TONING (CORNWELL-CLYNE) (TRANSPARENT)

Material

Positive (say Eastman Fine Grain Type 1302).

Processing Procedure

<i>Step.</i>	<i>Description.</i>	<i>Time.</i>
1	Development	6 mins.
2	Fixation	5 "
3	Wash	15 "
4	Harden	5 "
5	Wash	1 "
6	Bleach	5 "
7	Dye	1-2 "
8	Mordant	5-8 "
9	Rinse	10 secs.
10	Clearing	1 min.
11	Wash	1 hour
12	Final clearing	2 mins.
13	Rinse	

FORMULÆ

Development

Normal positive formula such as D76.

Fixation

Sodium thiosulphate 20%.

Hardener

Chrome alum, 5%.

Bleach

Potassium ferricyanide	..	..	..	..	10 gm.
Potassium iodide	..	..	..	..	10 "
Potassium thiocyanate	..	..	..	..	20 "
Water ..	..	..	..	..	1 litre

Bleaching should be continued until the silver image has entirely disappeared, leaving an extremely faint and perfectly transparent image. The wash which follows removes a slight yellow stain. The final appearance is faintly pinkish grey-brown. The image should be perfectly transparent against a dark background.

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Dyeing

Auramine O	20 gm.
Alcohol (Industrial)	1 litre
Water	1 „

Mordant

Potassium iodide	70 gm.
Potassium ferricyanide	10 „
Chromic acid	2 „
Potassium dichromate	5 „
Water	1 litre

The mordanting should be continued until a black *negative* image is obtained.

Clearing Bath

Potassium metabisulphite, 5%.

The yellow image is now visible in its final form, but the whites are fully dyed with the auramine.

Final Clearing Bath

Hydrochloric acid	50 c.c.
Water	1 litre

This bath is used if it is found that the whites are still stained after the wash which follows the first clearing bath.

On completion of all stages, if the image is still opaque in the shadows, a further increase in transparency may be obtained by re-immersion in the first bleach.

YELLOW COLOUR DEVELOPMENT OF BLUE-TONED IMAGE

Processing Procedure

<i>Step.</i>	<i>Description.</i>	<i>Time.</i>
1	Blue Toning	2½ mins.
2	Wash	8 „
3	Colour Development	5 „
4	Wash	7 „
5	Sodium Carbonate Treatment	1 „
6	Wash	3 „
7	Bleach	3 „
8	Wash	5 „
9	Fixation	3 „
10	Wash	10 „
11	Rinse (Distilled Water)	1 „

FORMULÆ

Blue Toner

See above.

Colour Developer (Yellow)*Solution A.*

Diethyl <i>p</i> -phenylenediamine hydrochloride	..	0.2 gm.
Sodium sulphite (cryst.)	.. .. .	8.0 "
Sodium carbonate (cryst.)	.. .. .	1.5 "
Water ..	.. .. .	100 c.c.

Solution B.

Furoyl-aceto-chloranilide	.. .. .	0.6 gm.
Ethyl glycol	.. .. .	5 c.c.
Methyl alcohol	.. .. .	5 "

Add B to A.

Sodium Carbonate Treatment

Sodium carbonate	50 gm.
Water ..	.. .. .	1 litre

Bleaching Bath

Potassium ferricyanide	.. .. .	60 gm.
Potassium bromide	.. .. .	16 "
Water ..	.. .. .	1 litre

Fixing Bath

Sodium thiosulphate	.. .. .	200 gm.
Water ..	.. .. .	1 litre

NOTE.—If lime salts deposit, add 0.16 gm. Calgon to No. 7A and 0.5 gm. Calgon to No. 9.

Printing-out Magenta (Martinez)

Water, distilled	.. .. .	450 c.c.
Gelatine	.. .. .	4 gm.
Ammonium oxalate	.. .. .	8 "
Potassium dioxalate	.. .. .	10 "
Ferric ammonium oxalate	.. .. .	15 "
Potassium bichromate	.. .. .	1.5 "
Oxalic acid	.. .. .	4 "
Sodium phosphate	.. .. .	2 "
Potassium carbonate	.. .. .	8 "
Potassium bromide	.. .. .	4 "
Ferric chloride	.. .. .	4 "
Mercuric chloride	.. .. .	21 "
Alloxan	.. .. .	24 "
Glycerine	.. .. .	11 c.c.

The ingredients are added or dissolved in the order named with the aid of heat. Suitable fixing agents are, for example, mercuric chloride, stannic chloride, silver nitrate, stannous chloride, etc. This formula gives an excellent magenta, but it is decidedly fugitive to light.

COLOUR CINEMATOGRAPHY

COLOUR DEVELOPMENT TO MAGENTA OF COMPLETED BLACK-AND-WHITE SILVER PRINTS, NAMELY, NORMAL RELEASE POSITIVES

Material

Normal positive fine-grain or otherwise.

Processing Procedure

<i>Step.</i>	<i>Description.</i>	<i>Time.</i>
1	Bleach	10 mins.
2	Wash	10 "
3	Colour development	5-7 "
4	Final bleach	3 "
5	Wash	5 "
6	Fixation	3 "
7	Wash	10 "

Bleaching Bath

Potassium ferricyanide	..	..	..	..	15 gm.
Sodium chloride	..	..	..	..	15 "
Water ..	..	..	..	..	1 litre

Colour Developer (Magenta)

Solution A.

Diethyl <i>p</i> -phenylenediamine hydrochloride	..	..	..	..	2 gm.
Sodium sulphite (cryst.)	..	..	..	..	80 "
Sodium carbonate (cryst.)	..	..	..	..	15 "
Water ..	..	..	..	..	1 litre

Solution B.

<i>p</i> -Nitro-phenylacetonitrile	..	..	..	..	6 gm.
Ethyl glycol	..	..	..	..	50 c.c.
Methyl alcohol	..	..	..	..	50 "

Add A to B.

An alternative to phenylacetonitrile is *p*-nitro phenylmethylpyrazolone.

Final Bleach

Potassium ferricyanide	..	..	..	..	60 gm.
Potassium bromide	..	..	..	..	16 "
Water ..	..	..	..	..	1 litre

Fixing Bath

Sodium thiosulphate	..	..	..	..	200 gm.
Water ..	..	..	..	..	1 litre

TONERS

FORMULÆ

Minus-Blue Metallic Toner (Transparent)

Vanadium oxalate solution*	..	..	..	50 c.c.
Oxalic acid, saturated solution	..	..	..	50 „
Glycerin	..	..	..	50 „
Water to make	..	..	..	1 litre

For use, add 1 part of 5% potassium ferricyanide to 100 parts of the above solution, and bathe the silver image until it is toned. Fix and wash thoroughly.

*NOTE.—To prepare vanadium oxalate solution:

Ammonium metavanadate or vanadium pentoxide	1.5 gm.
Oxalic acid	5.0 „
Water to make	50 c.c.

Heat and stir until a clear blue solution is obtained. The vanadate and vanadium pentoxide are poisonous.

Minus-Green Metallic Toner (1)

I.

Nickelous nitrate	..	..	..	..	50 gm.
Potassium citrate	..	..	..	..	150 „
Nitric acid (to acidify)	..	..	..	..	..
Water to make	..	..	..	..	1 litre

II.

Dimethylglyoxime (saturated solution in methyl alcohol)	..	..	..	..	100 c.c.
Sodium hydroxide	..	..	..	..	0.40 gm.
Water to make	..	..	..	..	1 litre

Bleach the silver image in a mixture of 5 parts water, 5 parts I, and 1 part 5% solution of potassium ferricyanide. Wash for at least 10 min., immerse in II until toned, fix in an acid fixing bath, and wash thoroughly.

Minus-Green Metallic Toner (2) (Creutz-Smith)

Sodium dimethylglyoxime	..	..	..	..	10 gm.
Nickel potassium cyanide	..	..	..	..	10 „
Water to make	..	..	..	..	1 litre

Bleacher

Potassium ferricyanide	..	..	..	..	30 gm.
Sodium carbonate	..	..	..	..	30 „
Ammonium nitrate	..	..	..	..	10 „
Sodium chloride	..	..	..	..	10 „
Water to make	..	..	..	..	1 litre

Bleach the silver image in above formula, wash for at least 10 min. Immerse in toner until toned, fix in acid fixing bath and wash thoroughly.

COLOUR CINEMATOGRAPHY

Minus-Red Metallic Toner

I.					
Potassium ferricyanide	..	..	..	..	30 gm.
Sodium carbonate	..	..	..	..	10 „
Ammonium nitrate	..	..	..	..	10 „
Sodium chloride	..	..	..	..	10 „
Water to make	..	..	..	..	1 litre
II.					
Potassium bromide	..	..	..	..	5.6 gm.
Ferric ammonium alum	..	..	..	..	5.6 „
Acetic acid, 100%	..	..	..	..	17 c.c.
Water to make	..	..	..	..	1 litre

Bleach the silver image in I for at least 10 min., immerse in II until toned, fix in an acid fixing bath, and wash thoroughly.

COLOUR DEVELOPMENT (DYE-COUPLING)

Dye-coupling is likely to be used to an increasing extent as a substitute for the older metallic toning in processes based upon the use of Eastman Duplitzed Positive Type 1509, either for two-colour subtractive prints or as a stage in the production of three-colour prints. The latter will require re-coating with emulsion for a third printing or bichromated gelatine can be used as in Chimicolor (French). The following data is for guidance only and many variations in the formulæ can be introduced without modification of the fundamental principles.

Developer

Diethyl <i>p</i> -phenylenediamine sulphate in 40 c.c. of					
methyl alcohol	..	..	..	..	2 gm.
Sodium sulphate (crystal)	..	..	..	..	10 „
Sodium carbonate (crystal)	..	..	..	..	80 „
Potassium bromide	..	..	..	..	2 „
Water to make	..	..	..	..	1 litre

Colour Coupler Stock Solution

Magenta	<i>p</i> -Nitrophenylacetoneitrile	..	..	10 gm.
	Methyl alcohol	..	..	1 litre
Yellow	2.5-Dichloroacetanilide	..	..	20 gm.
	Methyl alcohol	..	..	1 litre
Cyan	2.4 Dichloro-1-naphthol	..	..	20 gm.
	Methyl alcohol	..	..	1 litre

For use take

Magenta Colour Development	Developer	..	..	..	160 c.c.
	Magenta Coupler Stock Solution	..	..	..	5 „

Yellow Ditto ..	Developer	160 c.c.
	Yellow Coupler Stock Solution ..	5 „
Cyan Ditto ..	Developer	160 „
	Cyan Coupler Stock Solution ..	5 „

Bleach

Potassium ferricyanide	60 gm.
Potassium bromide	16 „
Water to make	1 litre

Fixing Bath (Alkaline)

Sodium sulphite	40 gm.
Hypo (Sodium thiosulphate)	240 „
Water to make	1 litre
Add formaldehyde	100 c.c.

Timetable

<i>Step.</i>	<i>Description.</i>	<i>Time.</i>
1	Colour Development, 65° F.	5 mins.
2	Wash	15 „
3	Bleach	5-7 „
4	Wash	5 „
5	Fix	10-15 „
6	Wash	30 „

Notes

It may be found that the hue of the cyan is insufficiently greenish to give a good neutral grey balance: in this event it is possible to shift the hue towards green by addition of the yellow colour coupler in small amounts until the desired hue is obtained.

A mixture of the magenta and yellow couplers will give a good two-colour red-orange and the cyan may be used unaltered or plus a small quantity of magenta to provide an accurate complementary to the red-orange.

Two-colour prints of fair quality can be obtained in *one layer* (on normal fine-grain release positive stock) by drying the film subsequent to the bleaching stage and re-exposing on the remaining silver halide. The second exposure will require at least twice the light of the first printing. The first print must be very thoroughly washed after bleaching, then dried, and re-printed in a register pin step-by-step printing machine without exposure to white light. The film may be safely handled in orange light.

COLOUR CINEMATOGRAPHY

ALTERNATIVE FORMULÆ

Dye-Coupling

Bleach

Potassium ferricyanide	..	..	..	..	30 gm.
Sodium carbonate	..	..	..	..	10 „
Ammonium nitrate	..	..	..	..	10 „
Sodium chloride	..	..	..	..	10 „
Water to make	..	..	..	..	1 litre

Colour Developer

Cyan I.

<i>p</i> -Aminodiethylaniline hydrochloride	..	..	..	..	3 gm.
Sodium sulphite	..	..	..	..	5 „
Sodium carbonate	..	..	..	..	50 „
Potassium sulphocyanate	..	..	..	..	0.5 „
Water, distilled, to make	..	..	..	..	1 litre

Cyan II.

<i>o</i> -Hydroxydiphenyl (or <i>m</i> -hydroxydiphenyl)	..	..	..	..	2.5 gm.
Alcohol, isopropyl	..	..	..	..	100 c.c.

For use, add 1 part B to 10 parts A. The mixture does not keep.

Magenta I.

2-amino 5-diethylaminotoluene hydrochloride	..	..	..	..	1.0 gm.
Sodium sulphite	..	..	..	..	10 „
Sodium carbonate	..	..	..	..	30 „
Potassium sulphocyanate	..	..	..	..	0.5 „
Water, distilled, to make	..	..	..	..	1 litre

Magenta II.

<i>p</i> -Nitrophenylacetonitrile	..	..	..	..	0.75 gm.
Acetone	..	..	..	..	20 c.c.
Alcohol	..	..	..	..	100 „

For use, add 1.5 parts B to 10 parts A. The mixture does not keep.

Yellow I.

Diethyl <i>p</i> -phenylenediamine	..	..	..	..	10 gm.
Sodium sulphite	..	..	..	..	5 „
Sodium carbonate	..	..	..	..	20 „
Potassium bromide	..	..	..	..	0.24 „

Yellow II.

Alcohol	..	..	..	..	50 c.c.
Acetoacetic ester	..	..	..	..	1.0 gm.

For use, add 0.5 part B to 10 parts A. The mixture does not keep.

Reference

NICHOLAUS, J. M., " Toning Positive Film by Machine Methods," *Journ. Soc. Mot. Pic. Eng.*, 29 (July 1937), p. 65.

The Processing of Two-Colour Prints by Deep-Tank Methods

CONSIDERABLE simplification of the processing equipment required for the usual metallic or dye-toned two-colour print on duplitized positive has become possible by the use of a protective coating which is impervious to the treating solutions and which can be removed easily without altering the characteristics of the treatment applied to the unprotected side of the film. This method permits the use of total immersion in the solutions at every stage of the process and thus eliminates the complex devices previously employed to apply a mordant to one side only of the duplitized film and similarly to apply in metallic toning, say, a solution to convert a silver image to a Prussian-blue image.

A modification of the Eastman Universal Protective Film Lacquer, originally developed by R. H. Talbot, of Eastman Kodak, has been successfully used for this purpose and the technique of application fully described by John G. Stott, also of Eastman Kodak.

A typical two-colour process is schematically set out as follows:—

<i>Step.</i>	<i>Description.</i>	<i>Image.</i>
1	Develop in black-and-white developer ..	Silver on both sides of film
2	Stop and fix in hypo.	
3	Wash	
4	Treat <i>one side</i> of film in iodizing mordant	Dyed silver iodide on one side of film and silver on other side
5	Clear in bisulphite solution	
6	Wash	
7	Dye silver-iodide image	
8	Wash or backwash in acid	
9	Immerse in Prussian-blue toning solution	Dyed silver iodide on one side of film and Prussian-blue on other side
10	Wash	Silver iodide removed as well as silver ferrocyanide in Prussian-blue image making images transparent
11	Fix and harden	
12	Wash	
13	Dry	

COLOUR CINEMATOGRAPHY

Step 4 requires special apparatus and many methods have been devised by Kelley, Brewster, Capstaff and others. The step is always difficult and flotation systems involve serious danger of solutions getting on to the wrong side of the film. Step 7 can be performed by total immersion as the dye will act only upon the mordanted silver. The film can also be totally immersed for Step 9 because the toning solution has little or no effect upon the dye-mordanted image.

NEW PROCESS

<i>Step.</i>	<i>Description.</i>	<i>Image.</i>
1	Develop in black-and-white developer ..	Silver on both dies of film
2	Stop and fix in hypo.	
3	Wash	
4	Dry	
5	Apply protective coating to one side of film	
6	Dry	
7	Iodize in deep tank by total immersion ..	Dyed silver iodide on one side of film and protected silver image on opposite side
8	Clear in bisulphite solution	
9	Remove protective coating	
10	Wash	
11	Dye silver iodide image	
12	Wash or backwash in acid	
13	Immerse in Prussian-blue toning solution	Dyed silver iodide on one side of film and Prussian-blue image on opposite side
14	Wash	Silver iodide removed as well as silver ferrocyanide in Prussian-blue image making final images transparent
15	Fix and harden	
16	Wash	
17	Dry	

As the Eastman lacquer mentioned is alkali-soluble it will remain unaffected by immersion in the iodide mordanting bath and yet be removable in an alkaline solution which does not injure the iodized image. The lacquer must be "bead-applied" with a coating thickness of 0.0002 in. One gallon will coat 10,000 feet of film (Fig. 316). The lacquer must be applied to dry film and "may be installed in the drying cabinet of the black-and-white stage of the process such that several drying loops are available after the application of the lacquer to dry the coating properly."

Experiments have shown that the lacquer may be bead-applied well into the perforation area without danger of leakage of the lacquer through the perforations (Fig. 317).

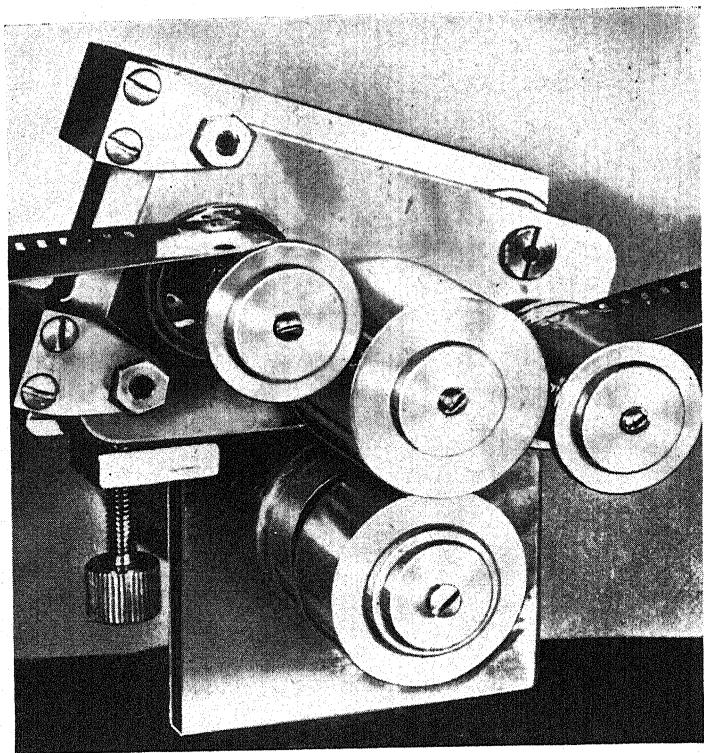


FIG. 316.—Apparatus for “bead” application of lacquer to film.

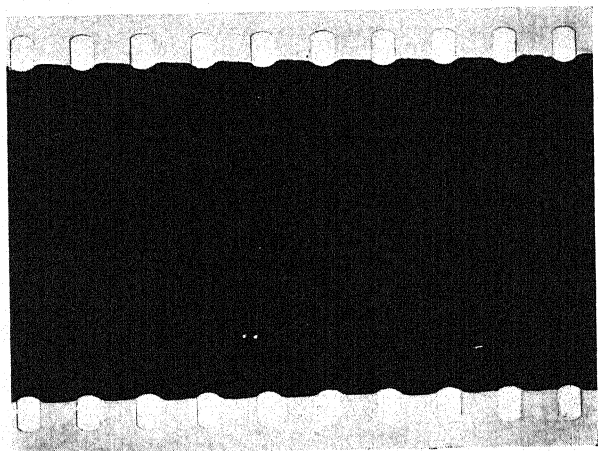


FIG. 317.—Darkened portion of film indicates area to which lacquer is applied by head applicator.

(Facing p. 612)

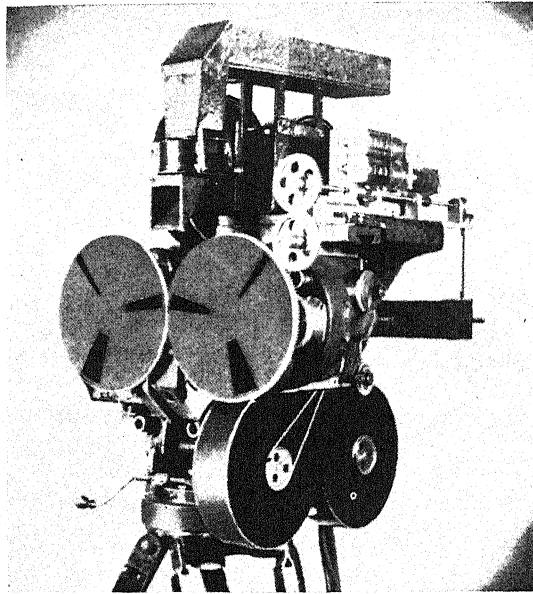


FIG. 320.—Stereoscopic colour camera. (See p. 616.)

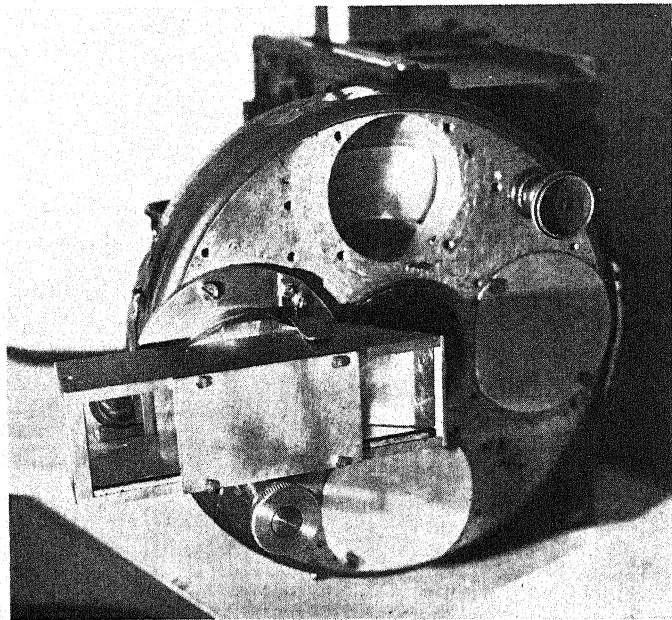


FIG. 321. (See p. 617.)

THE PROCESSING OF TWO-COLOUR PRINTS

Processing solutions should be carefully filtered to avoid pinholes arising from minute particles of dirt.

The lacquer is removed by immersion in a 2% solution of sodium carbonate for two minutes followed by a two-minute wash. The solution should be replenished at a rate adequate to prevent sludge accumulating.

If Prussian-blue toning is carried out first the alkaline solution of lacquer-remover will convert the ferric ferrocyanide to ferric hydroxide, which is brownish. This can be reconverted by immersion in a bath of acid ferrocyanide, which will add two more steps including a wash to the sequence of operations.

Obviously many alternatives suggest themselves and there is no doubt that the lacquer resist technique offers interesting scope for the invention of new treatments.

Reference

STOTT, JOHN G., "The Processing of Two-Color Prints by Deep-Tank Methods," *Journ. Soc. Mot. Pic. Eng.*, 49, 4 (Oct. 1947), pp. 306-315.

The Stereoscopic Motion Picture in Colour

WE are not concerned in this treatise with the optical and geometrical problems of stereoscopic projection, which are difficult to comprehend without actual demonstration and would require many pages for adequate treatment. But reference should be made to colour photography in relation to stereoscopy because the inclusion of colour in a stereoscopic image enormously emphasizes its realistic effect. The addition of apparent depth, of course, constitutes a further step towards the achievement of an absolute illusion of reality. Whereas the convention of the monochromatic image is artistically acceptable providing that the depth effect is in equivalently conventional terms, the presence of a complete illusion of three dimensional projection so increases the sensation of reality as to constitute a contradiction which defies the laws of artistic unity. Solid human figures in grey become ghostly dummies. It follows that the mind *expects* the image to be coloured as soon as it is perceived as a solid in full projection.

It should be unnecessary to state that genuine stereoscopy is only possible by conforming to the fundamental requirement that the right and left eye of the observer must respectively perceive geometrically different images parallaxically displaced by the inter-ocular (or a greater distance may be adopted) distance. The most elegant solution of this problem so far discovered is the projection of pairs of stereo images with polarized light.

If paired projectors are arranged to project stereo pairs of images, the respective projection lenses may be equipped with polarizing filters with their polarizing planes respectively at 90° to each other. The observer requires a pair of viewing polarizers (spectacles or goggles) with their right and left eye planes of polarization corresponding with those chosen for projection of the right and left eye images (Figs. 318-319).

Normal diffusely reflecting screen surfaces depolarize incident polarized light; it is therefore necessary to employ partially specular reflection and, for this purpose, aluminium paint or lacquer has been found effective. The inevitably narrow angle of reflection obtained with this type of screen is a serious disadvantage. Glass bead screens are not quite as good but they are reasonably efficient.

The remarkable Technicolor stereoscopic film presented by Chrysler

THE STEREOSCOPIC MOTION PICTURE IN COLOUR

at the New York World's Fair in 1939¹ is the largest scale public exhibition of three dimensional motion pictures so far given. The film had a projection length of some 15 minutes and consisted of a stop motion sequence in which the parts of a Plymouth automobile march, dance or sail into their correct position in the chassis in time with the musical accompaniment. The scenario was written by J. A. Norling of the Loucks and Norling Studios in New York. Norling also did the

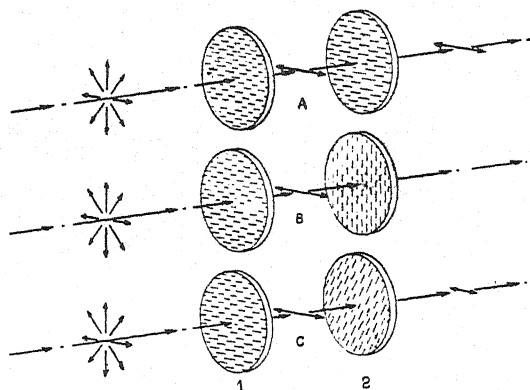


FIG. 318.—Illustrating the effect of plane polarization.

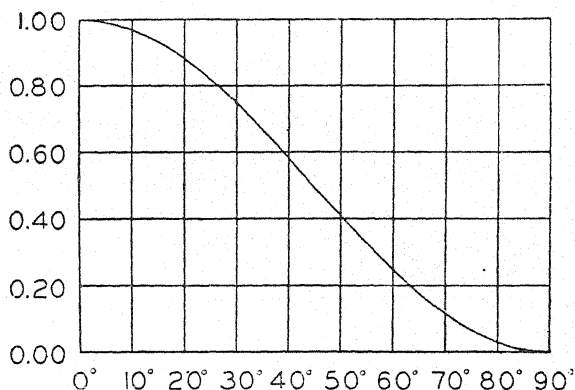


FIG. 318A.—Relative transmission of light through superposed polarizers.

whole of the technical control. Part of the film—the part using living models—was made with a pair of Technicolor beam-splitter cameras, but the mechanical animation was photographed with a pair of cameras using single film and successive sets of Red, Green and Blue frames. The negative film stock was Eastman Kodak, Type 1230. Lighting was provided by 3,200° K. Tungsten filament lamps without filters. Maxi-

¹ 1,500,000 persons saw this film. The first showing was May 4, 1939.

imum permissible voltage variation was 2 volts in 112. Each camera was equipped with a rotating filter disc with angular sectors of R, G, B, balanced to give 1:1:1 as the product of light and emulsion sensitivity. With Wratten filters, A, B and C5 the sectors were 2.5° Red, 7° Green and 18° Blue.

Consisting of a pair of film paths, pull-down mechanisms and matched lenses, the camera was essentially two normal cameras on a single base. Their optical systems could be made to converge at any point from infinity to a certain minimum distance. The inter-ocular distance could be varied and the focusing mounts were interlocked (Fig. 320).

The aperture plates normally lay in the same plane, but the optical systems could be toed in if desired to compensate for the keystone effect from the toeing in on the two projectors. Inter-ocular distance

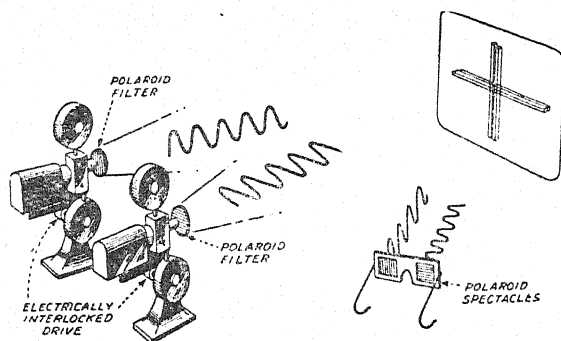


FIG. 319.—Diagram of a double projector installation using "Polaroid." (Courtesy Photo-Technique.)

could be varied from 2.5 to 5 in. The former value was used throughout the film.

The convergence point must in general be *nearer* than any object in the scene because it determines the location of the "window" through which the action apparently takes place. In a medium close-up the convergence was eight feet from the camera. Thus, action occurring beyond eight feet appeared to be behind the field frame. Any object approaching the camera nearer than eight feet will apparently project in front of the screen. For a long-shot sequence the axes converged at 17.5 feet.

Both 50 mm. and 35 mm. matched lenses were used and the required depth of field was obtained at an aperture of $f/6.3$. The focal lengths of matched lenses used for stereo must not exceed plus or minus 0.1 mm. in a focal length of 50 mm.

In projection two standard projectors were used. To allow the operator to walk between these, they were placed five feet apart and the optical axes converged such that the images of their *apertures* coincided at the screen. Synchronism was obtained with Selsyn motors.

All who were privileged to see this film were greatly impressed and it is a great pity that the successful achievement of genuine stereoscopy is unlikely to find general appreciation in commercial entertainment owing to the insuperable difficulties presented by the necessity of using a visual analyser in the form of a pair of spectacles, a goggle, or a plastic mask of some description. The trade has no clear idea as to how such spectacles could be distributed to an audience, how collected after use, and sterilized before re-issue. Furthermore, no producer would contemplate making a stereo version of a film without the certainty of wide distribution. So special are the photographic limitations that it is unlikely that it would be possible to include a stereoscopic take while making a normal record. The existing screens are useless as they would depolarize the light, and for rapid changeover four projectors are needed. Finally, for adequate screen reflectance from a semi-specular surface only a narrow viewing angle is available, and for correct geometrical projection one cannot approach near, or recede further from, the screen than within rather restricted limits, otherwise the apparent scale of the object undergoes strange transformations either appearing of gigantic size or of Lilliputian proportions. For these and other reasons this method is likely to be restricted to the home, or to specialized industrial and scientific applications.

For sub-standard projection it is relatively simple to design simple beam-splitting devices, enabling the pair of stereoscopic images to be placed side by side by dividing the standard frame vertically, although the projection frame will in this case have its longer dimension vertical, which is pictorially unsatisfactory with most subject matter.

Similarly obvious devices are such as the recording of sub-standard pairs of the normal proportions side by side within the area of the normal 35 mm. projection frame, but this involves a projection system identical to that required for two-colour additive systems, and necessitates considerably greater enlargement of the film image (Fig. 321).

In the present state of knowledge, it is absurd that inventors and their backers continue to announce the successful achievement of stereoscopic projection systems requiring no special projection, no visual analysers, no special screen and so forth. Such claims can be immediately dismissed as either fraudulent or arising from the phenomenon that apparently large numbers of people are almost entirely deficient in stereoscopic perception, amongst which deficient we must include the inventor. Most proposals of this kind resolve themselves into effects known as pseudoscopic, as for example, the continuous lateral displacement of an image, to and fro, which conveys a sense of depth by the observation of parallax movement of objects relative to one another.

Colour photography in any case increases apparent stereoscopy by use of the illusion of projection resultant from the opposition of warm

COLOUR CINEMATOGRAPHY

colours generally to cold colours, namely of reddish to bluish colours. The warm colours tend to project and the cold to recede, partly owing to association with the effects of aerial perspective and partly owing to the chromatic aberration of the eye.

References

- "Stereoscopic Movie in Color," *Photo Technique* (Feb. 1941), p. 30.
RULE, JOHN T., "The Geometry of Stereoscopic Projection," *Journ. Opt. Soc. Amer.*, 31 (1941), pp. 325-334.
JUDGE, A. W., "Stereoscopic Photography," Chapman and Hall Ltd., London (1935).
KENNEDY, C., "The Development and Use of Stereo Photography for Educational Purposes," *Journ. Soc. Mot. Pic. Eng.*, 26 (Jan. 1936), p. 3.
NORLING, J. A., "Three-Dimensional Motion Pictures," *Journ. Soc. Mot. Pic. Eng.* (Dec. 1939), pp. 612-634.

Make-up

THERE is no standard make-up to be obtained from one jar and applied to all complexions for colour cinematography. Each individual must be considered separately. These are two guiding factors for consideration:

1. The natural colouring of the individual which must form the basis on which to work.
2. The type of character to be portrayed.

According to these are determined the amount of make-up and the actual tones of make-up used.

Instructions on Application of Make-up

It is important that the light under which the colour make-up is done is daylight, or a good artificial daylight. Special glasses can be obtained on application to Dufay-Chromex for use by the make-up artist, which will enable him to see his work exactly as it will appear on the screen.

Applying Cake Make-up

First clean the face with melting cream, and wipe clean with soft tissue. Pat on a tiny bit of skin refreshener. Then moisten the sponge, squeezing out the surplus water. Rub sponge firmly over cake and apply to the face, beginning with the forehead. You can either wait for it to dry, or pat gently with soft tissue, which will hasten the drying process. Then brush over with a powder brush, and complete your make-up as usual. All areas of flesh visible to the camera must be made up in accordance with the individual make-up. It is important that this should be applied directly and evenly, and then brushed over. Quantity of pancake used is as required.

Applying Lining Colours

Before applying, the lining colour should be softened with cream, reducing the present consistency about 50 per cent. Then apply by patting. Do not rub.

Powdering

For colour make-up neutral tints only are used. Powders the same tone as the foundation are generally used. The purpose of powdering is to help the texture of the skin, *i.e.*, to give a matt surface, and it has nothing to do with the colour of the skin. In some cases little or no powder is required, *i.e.*, for some characters a slightly greasy texture is preferable. Before applying the powder, be sure that the make-up is thoroughly dry, then, with a powder brush, brush briskly to remove all surplus make-up. The brushing helps to smooth the entire surface area, and also to remove any surplus amount which would ordinarily appear too heavy. Then powder by patting it over the entire area lightly, using about one-third of the usual amount that is used in comparison with grease paint make-up. After you have powdered, again brush with your powder brush—this time lightly.

Applying Rouge

Dry rouge is the most satisfactory for females. The dry rouge for the cheeks is applied with a powder brush, and is blended so that there will be no demarcation on the edges. Grease rouge is better for males. This should be stippled on. Use only sufficient colour for street make-up. Watch the complexion carefully during shooting, since changes may occur.

Applying Lip Rouge

Apply the lip rouge in the usual manner, but sparingly. There should only be enough lip rouge colouring to cover the natural lip pigment. If, in applying, there is a surplus of rouge on the lips, remove by inserting a tissue and impressing the lips on this tissue, which will absorb the excess quantity. Lip gloss used sparingly is advised. This helps to keep the lip rouge even in appearance, and prevents caking.

Applying Highlight and Shadows

Whenever it is necessary to use highlights or shadows apply it to the areas before using the base colouring. In other words, the highlights and shadows are underneath the base make-up. The highlights or shadows can be applied with a water-colour brush. The brush is first moistened and then rubbed into the proper colouring of cake make-up, and then applied to the necessary areas. Have this thoroughly dry before applying the base make-up. The base make-up will not smudge the highlights or shadows.

Use of Grease Paint

Grease paint is never used as the foundation in place of pancake for Dufaycolor. It can be used in certain cases for highlights, shadows, to

cover scars, etc., but then only in very small quantities. The same range of tones is used as in pancake.

Sponges

The selection of sponges is very important. Be sure to select a fine grain sponge of a very soft, silky texture, and if possible the type that has not been bleached.

Artificial Eye Lashes

If required these can be used quite satisfactorily.

General Remarks

A colour make-up is best an hour to two after application, when traces of noticeable artificiality disappear, and the natural skin texture of the individual comes through the make-up. The make-up has by that time become part of the individual. Usually a make-up will last for the whole day's work. It can be re-touched and repaired as necessary.

The above outline applies to straight make-ups for colour cinematography. The same principles apply to character work; the more natural in appearance and colour these can be made to look the more satisfactory the result.

MAX FACTOR'S MAKE-UP FOR COLOUR FILMS

Women.

For Normal Complexions	No. 21M Pancake
For Drab and Yellow Complexions	No. 21L "
For Brunettes—Very Fair Complexions	No. 21R "
Sallow or Dark Complexions	No. 24G "
For Blondes—Very Fair Complexions	No. 21R "
For Highlights	No. 21P "
For Shadowing	No. 24H "
For Powdering	No. 1A Neutral Powder
For Lips	Vermilion and Carmine lipstick
For Cheeks (dry rouge)	Carmine rouge
For Eyes	No. 6 Eye Lining

Men.

For Normal Complexions	No. 24H Pancake
For Very Dark Complexions	No. 24K-24L or 25HY Pancake
For Fair Complexions	No. 24G
For Shadowing	No. 25HY
For Highlights	No. 21M
For Extreme Highlights	No. 21P
For Powdering	No. 3A Neutral

ELIZABETH ARDEN'S MAKE-UP FOR COLOUR FILMS

Foundation

- All-day Foundation .. Rose Rachel for blonde or medium colouring, Redhead for darker complexions, or to give a glow to a pale one.
- Pat-a-Crème Rose Rachel for blonde colouring, or to give a light effect. Light Rosetta for medium or darker complexions.

Rouge and Lipstick

Colours are chosen to harmonize with the colour of the costume.

- Burnt Sugar A brownish red for use with costumes in brown, maize, rust, tan, olive green. Good also for redheads.
- Cinnabar Drama .. Rich reds for dark colours. Also for brunette colouring.
- Red Feather Clear, bright reds for use with neutral colours, matching reds, gray, beige, certain yellows and greens, but not mauvish blues. Good with average complexion.
- Royal
- Stop Red
- Montezuma Red ..
- Paradise Pink Bluish reds—for use with costumes in wine, fuchsia and cyclamen shades. Black, white, mauvish blues. Paradise Pink is very good with bright pinks and pastels.
- Radiant Peony
- Cyclamen
- Red Cactus

Eyeshado

- Brun Clair A soft greyish-brown eye-shado.
- Drama Muted green-brown with gold glints.
- French Grey Blue-grey.

These eye-shados are good for use over the whole lid with brighter colour over the pupil.

Brun Clair for brown eyes and with a make-up in clear red.

Drama for any colour eyes—for a dark toned make-up.

French Grey—specially good for a pastel make-up, and for grey or grey-blue eyes, for the woman with grey or white hair.

More colourful eye-shados for use in combination with above.

- Bleu Vert A greenish blue.
- Sea Blue Pale blue.
- Malachite Bluish green.
- Bleu Corbeau Deep blue.

ELIZABETH ARDEN'S MAKE-UP FOR COLOUR FILMS—*Continued.***Eyelash Cosmetique**

Black	Used according
Brown	to natural colour
Blue-black	of the lashes.

Powders

Special Rachel.. ..	For blondes and for a pale make-up.
Rose Mist	Used as a first powder <i>under</i> for a pink tones make-up worn with pastels.
Special Mat Foncé	Average skins.
Banana	For fair, creamy skins.
Lysetta over Mat Foncé	A pink toned powder to give warmth to a pale skin. Used as a make-up to wear with blue or wine shades.
Rose Rachel	A deeper powder to give warmth to the skin, especially to brunettes. Good with colours such as mulberry, dark furs, or as a contrast with white and bright coloured summer costumes.
Rosetta Bronze	For a sun-tan effect. Used over a lighter powder it is effective for a make-up for a honey-blonde with white, brown or green, or for a darker complexion with brilliant colours.
Light Summer Sun	Dark sun tan.

Colour Sensitometry

WE have already made clear that the requirement for a recording material is that its sensitivities should conform to visual mixture curves for the spectral regions, modulated respectively by the three subtractive primaries of a given positive process or material, and that in a coloured multilayer negative the colours may be what we will providing that they are such as can be "seen" only by the duly assigned layer.

Obviously, visual sensitometry of such a negative material cannot be founded upon neutrality since such a negative could bear a record of a neutral wedge in the form of a strongly coloured image. The characteristics of each layer could only be explored by a triple photo-electric system trimmed to "see" the negative as the layers of the chosen positive print material are destined to.

In fact, visual sensitometry of a coloured negative material is impracticable unless we assume a spectrally non-selective neutral grey scale in the negative results from the combination of the three dyes embodied in its layers and that these greys are "seen" in precisely the same manner by each layer of the positive.

The positive material is to be viewed by the human eye and the problem of its *sensitometry* is strictly the concern of the manufacturer in the case of multilayer materials; whereas in printing processes carried out in the laboratory control may be by conventional densitometry as in the case of Technicolor, or by methods analogous to colorimetry for processes like Dufaychrome or Gasparcolor.

We know that ideal subtractive dyes or colouring agents do not exist. If they did exist then the colour density of a dye would be a measure of its absorption in the region of the spectrum it is intended to modulate. Its density for that region could be determined by means of a filter transmitting only in that region. Thus yellow would be measured with a narrow-cut blue filter, cyan with a red filter, and magenta with a green filter. However, the dyes available only roughly approximate to the ideal. The spectral distribution of energy of the light transmitted by their integrated absorptions yields generally a triple humped curve. This integrated transmission stimulates an achromatic sensation at a certain balance of densities for the three dyes chosen, but if the densities of the three dyes are reduced linearly the integrated transmissions may no

longer yield spectral distributions which stimulate grey sensation. In general, therefore, we cannot apply assumptions derived from experience with the silver deposits of the black-and-white photographic image. The assumption therefore that the sensitometric curves of three dye images should be coincident in order to yield neutrality is false, and little valuable information can be derived from constructing the conventional curves representing the relation between log exposure and the corresponding density. (The H and D curve.) If this is done it soon becomes evident that a satisfactory grey scale is rendered by three curves which may depart considerably from coincidence.

G. Heymer and D. Sundhoff (1) were the first to point out that a new quantity was required which would yield identical values for the three subtractive primaries when their combination at certain concentrations yields visually neutral colour. (Depending, of course, on the spectral distribution of energy of the light source.) They called this quantity

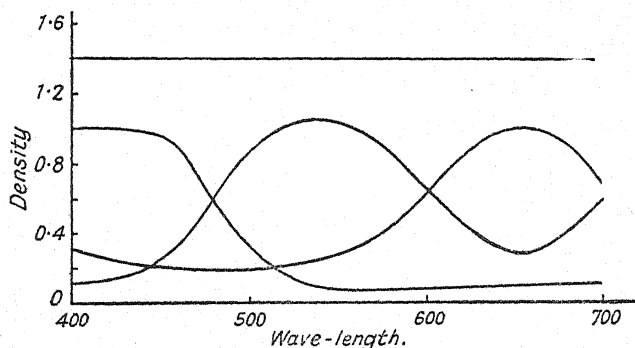


FIG. 322.—Effect of impurities upon combined density (R. M. Evans).

“grauaequivalente teilfarbdichte,” or “equivalent density.”¹ This is the visual density any colour used in a subtractive process would have if it were neutralized by superimposition of the just required amounts of the other two colours *used in that process*.

R. M. Evans (2) of Eastman Kodak has described a colour densitometer which can be used for determining equivalent densities. He points out that at first sight it would appear that equivalent density must be the density a colour would have if it were subtractively combined with its exact complementary. But this is not the case because:

“If three dyes are chosen which in a certain ratio give neutral grey, the visual density of this grey is greater than the maximum absorption density of any one of the dyes at any wavelength. This is due to the so-called ‘impurity’ of the colours and is illustrated by the arbitrarily drawn curves of Fig. 322. In this figure the density of each dye at each wavelength is plotted separately, the density at each wavelength being defined as in the case of silver images. (This is possible because

¹ The term “grey-yield” is better English and preferred by the author.

the relative sensitivity of the eye to *different* wavelengths does not enter.) The density at each wavelength for the three dyes combined may then be obtained by adding the three curves at each wavelength, just as neutral densities may be added. Since the three dyes have been chosen to give a neutral grey when mixed, the point-by-point addition of the curves gives rise to a fourth curve which is at essentially the same density at all wavelengths. Being the same at all wavelengths, this density is the value that would be read by white light on a densitometer. Note, however, that since each of the dyes has a definite density at *every* wavelength, the final neutral density is higher than any point in any of the curves. If the exact physical complementary for any of the dyes were added to that dye, nothing would have been added to its *maximum* density and the final neutral density would have been *less* in such a case than in the case of the three actual dyes."

Any change in the concentration of a dye would involve a change in its complementary. Accordingly visual measurements of density by means of an arbitrary filter are unrelated to dye processes.

Equivalent density or "*grey-yield*" for each step of a wedge in one of the constituent subtractive primaries (say, magenta) is the density formed when the required amounts of the other two colours are superimposed on each step to yield neutrality. Such densities mean that when equal densities of all three dyes are superimposed the result is a neutral grey equal in density at each step to the other two recording elements in the subtractive structure.

Evans has adapted the Capstaff-Purdy densitometer in which the image, being measured, is placed in a beam of light in series with a circular calibrated neutral wedge of graduated density (Fig. 323). "By another path, light from the same source is brought around the wedge and both beams of light enter an eyepiece in such a way that comparison of the brightnesses of the two may be made to high precision. The brightness of the unimpeded beam due to the length of its path is made less than that of the wedge beam in a known ratio. In other words, it requires a definite density of, say, 3.4 in the path of the light through the wedge to make it equal the brightness of the comparison beam. The density of the unknown sample may be determined by moving the wedge until the two beams match. At this point it is known that the sum of the density of the wedge and the unknown equals 3.4 and the instrument may be calibrated to read the difference between this and the actual wedge density, or the density of the unknown." The advantage is that the field brightness when the beams are matched is always the same. Plus the grey wedge, three additional wedges are used made in the actual three element colours of the process.

To measure a colour deposit (one of the subtractives, say, *yellow*) the film is placed in beam C with all wedges at a maximum transmission. The neutral wedge is then rotated to equate the brightness of the two

halves of the field. Next each of the other two wedges (namely, the cyan and magenta) is rotated until the transmitted light appears grey. The brightnesses of the two halves of the field are then matched and the density is then read from the neutral wedge scale.

Evans notes: "If the colour is not a deposit of one colour record alone but a mixture of two or of all the records, the density may still be

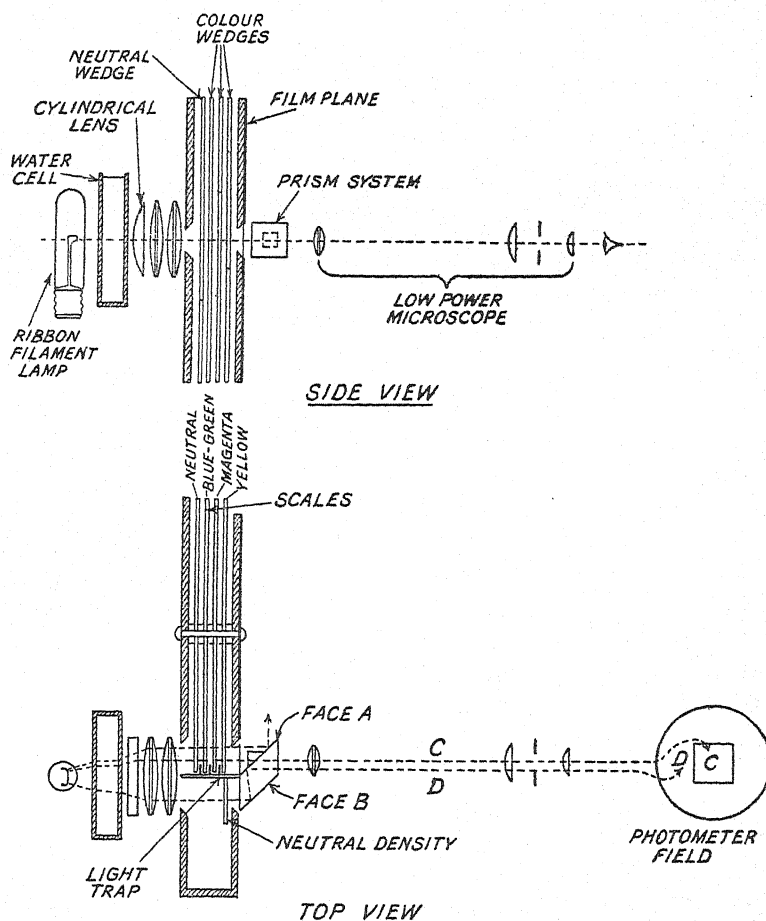


FIG. 323.—Schematic arrangement of colour densitometer (R. M. Evans).

determined and is of equal validity to that read from a deposit of a single colour if care is taken to add in only those colours in which the original is deficient. Where the density corresponding to one colour record is all that is desired, there is no need for calibration of any of the colour wedges. It is within the capacities of the instrument, however, to calibrate itself, and when this is done it becomes possible to determine

the equivalent density of *each of the colours in any mixture*. This makes it possible to determine the curves for each colour record from a single photograph of a neutral scale or, more conveniently, from a single exposure to white light in a sensitometer of the conventional type."

"The calibration and application of the instrument for this purpose is carried out as follows: Arbitrary scales are attached to each of the colour wedges. If wedge C is to be calibrated, it is set at the first division of its arbitrary scale, say, ten degrees from the point at which the wedge has no colour. The other two wedges are then rotated until the light passing through is grey, the brightness of the beam is matched to that of the comparison beam, and the 'equivalent density' read from the neutral

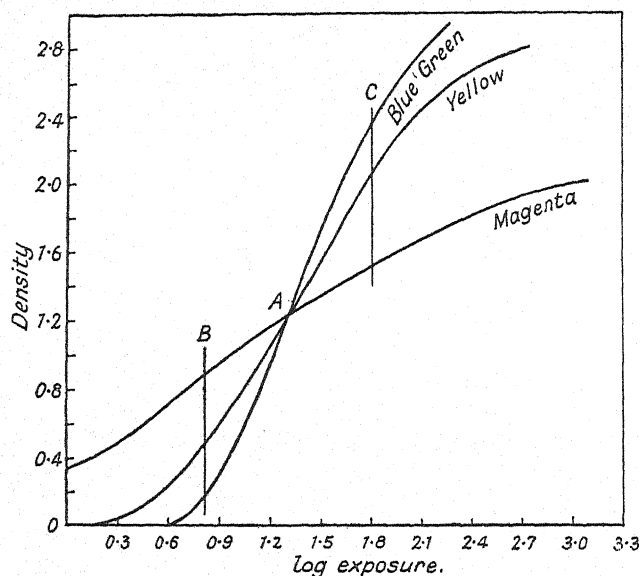


FIG. 324.—Colour density curves of a sensitometric strip (R. M. Evans).

wedge is applied to the wedge being measured. In other words, each wedge at successive points is considered as a sample to be measured, and in this way each is calibrated. Any colour may now be specified in terms of the equivalent densities of each of its components. To do this the sample is placed in the beam as usual; the wedge corresponding in colour to the predominant colour of the sample is left at zero, and sufficient of each of the other colours is added by means of the wedges to give a neutral which is then balanced with the neutral wedge. The neutral wedge now reads the equivalent density of the colour present in the greatest amount, and the densities on the other two wedges, subtracted from this value, give the equivalent density of each of the other colours present in the sample."

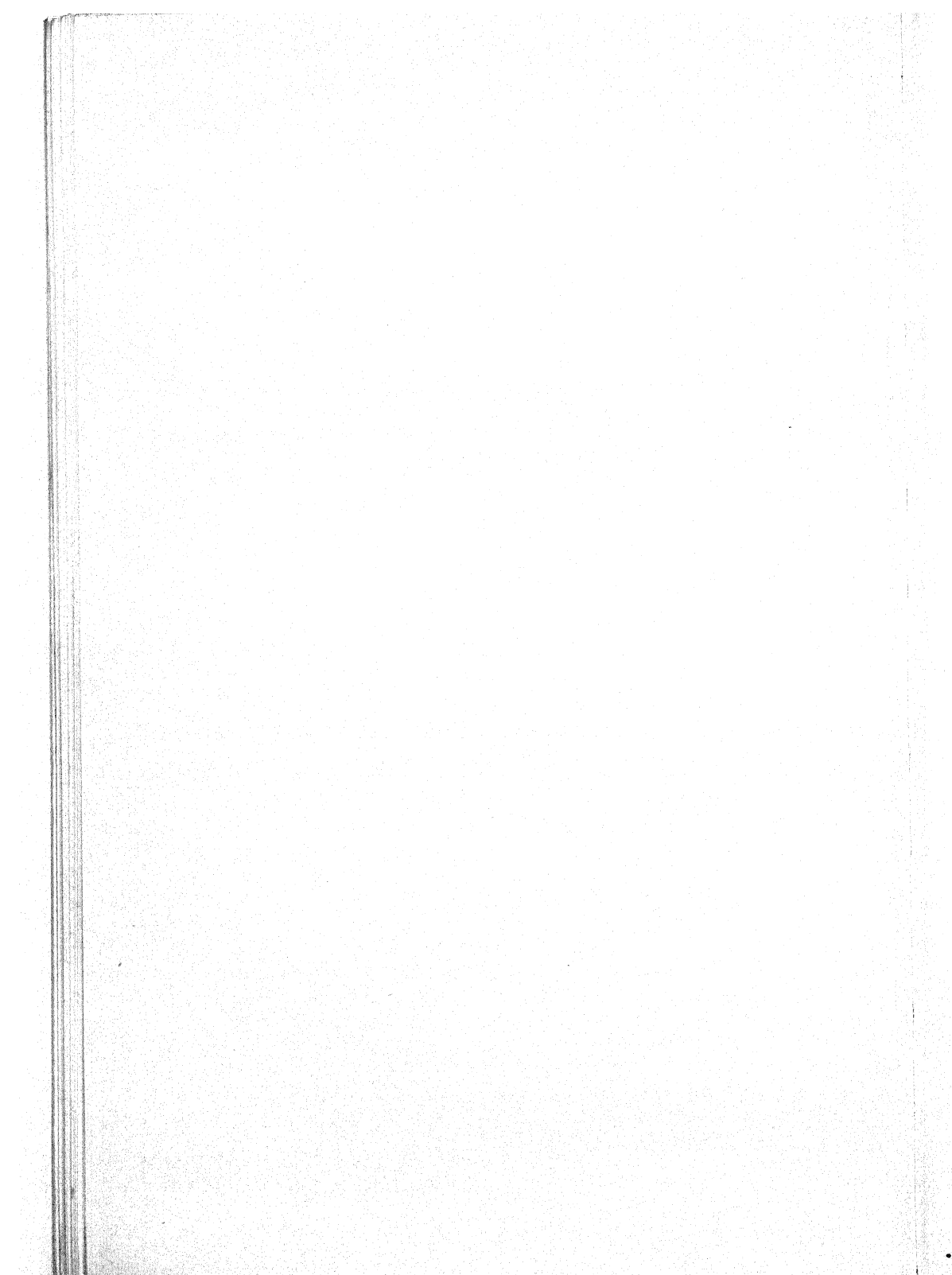
If a sensitometer strip is exposed by white light and the resulting steps are read, the curves of each colour may be plotted independently. Fig. 324 shows colour density curves read on a colour densitometer of the type Evans describes. They are chosen deliberately to exhibit an unbalanced process. The scale appeared neutral at step A, red at step B, and green at step C.

Obviously such an instrument must be fitted to each process, the wedges being made by the process, and "the inter-changeability of colours at the wedge and sample positions must be checked over a sufficient range before the results can be expected to yield useful information in the control and adjustment of the process."

As M. H. Sweet (3) reminds us in discussing equivalent density: "It can be readily understood that for every different combination of densities of the three dyes there will be a unique set of three integral density readings and a corresponding set of equivalent density values. Those familiar with masking processes may grasp the principles involved, in fact, the three equations (all linear) which show the relationship between the equivalent density and the integral density readings are identical with those used in connection with the automatic masking technique in subtractive colour processes" (4).

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- (1) HEYMER, G. and SUNDHOFF, D., "Measurement of the Gradation of Color Film," *Veroffen wiss. Central-Lab. Phot. Abt. Agfa*, 5 (1937), p. 62.
- (2) EVANS, R. M., "A Color Densitometer for Subtractive Processes," *Journ. Soc. Mot. Pic. Eng.*, 31, 2 (Aug. 1938), p. 194.
- (3) SWEET, M. H., "The Densitometry of Modern Reversible Color Film," *Journ. Soc. Mot. Pict. Eng.*, 44, No. 6 (June 1945), p. 419.
- (4) KRAUSE, P. and VARDEN, L. E., "The Sensitometry of Multilayer Color Materials," *Amer. Photography*, 42, No. 11 (Nov. 1948), p. 680.
- (5) KECK, P. H., "Color Reproduction by Color Photography," F.I.A.T. Final Report No. 977 (May 1947).



PART THREE

Man in general experiences great joy in colour. The eye needs it as much as it does light.

GOETHE.

The Phenomena of Colour Vision and the Making of Films in Colour

AFTER-IMAGES

If we gaze steadily at a fairly bright patch of white light for a few seconds and then close the eyes we can see an image of the shape of the patch persisting. Such a persisting sensation is called an "after-image." The evidence supports the opinion that it has its origin in the retina. For instance, if we expose one eye only to the stimulus we shall find that an after-image is confined to that eye only. If the original stimulus was intense enough it will be observed that various changes occur in the colour of the after-image. Next we find that if we submit to the eyes the same stimulus, but this time keep the eyes open and turn the gaze to some uniform background, say of white or grey, we can still see the after-image superimposed upon it. Since the colour film will often present rapidly varying stimuli to the eye, it is well that we should be acquainted with the phenomena of after-images, as it should thus prove possible to emphasize colour contrasts, and thereby to predict the æsthetic effect of certain sequences. The nature of the after-image depends upon the quality and the intensity of the first stimulus, and upon the quality and the intensity of the secondary background.

After-images are of two kinds, positive and negative. If we look for a few seconds at a white spot and then direct the gaze upon a white surface, a black spot surrounded by a halo will be seen. This is the *negative* after-image. If the original spot is coloured the after-image will be observed to be tinged with the complementary colour. Under other conditions, if a brightly illuminated spot is seen only momentarily, the after-image will be seen as an illuminated area. This is a *positive* after-image, and if the first stimuli is coloured the positive after-image will be similar in colour. Both positive and negative after-images are continually present in our normal visual field. After-images persist much longer than is generally supposed. A patch of 10 foot-lamberts luminance if gazed at for half a minute will leave an after-image which will persist for five seconds.

A bright patch of white will leave an after-image which, though at

first white, will later pass through a regular sequence of colour changes. These changes are generally in the order: white—greenish white—green—red—blue—green—red—blue, over a period of several seconds. (During this period the image is positive, afterwards it changes to a negative after-image, which may have a halo in the complementary colour to the colour which the spot assumes at any moment.)

The effects are complicated and exhibit divers phenomena, but the principal fact for us to remember is that the first after-image of a colour stimulus is approximately complementary to it, thus:

<i>Original Stimulus.</i>	<i>After-Image.</i>
Red	Blue-Green
Orange	Peacock Blue
Yellow	Blue
Green	Purple
Blue	Yellow-Orange, etc.

These after-images are not exactly complementary to the original excitation, and they are negative after-images. If we look fixedly at a patch of vivid colour and observe the after-image upon another colour we find that the colour of the after-image approximates to that colour which would result from subtracting the colour of the first stimulus from that of the secondary background colour. The effect is somewhat like that of an absorption filter except that the after-image is often lighter than the background. The following effects are found (Table 39):

TABLE 64

<i>If we gaze first at:</i>	<i>And afterwards upon:</i>	<i>It will appear:</i>
Red	Red	Lighter and Greyer.
	Orange	Greenish and Desaturated
	Yellow	Vivid Green
	Green	Vivid Green and more Blue
	Blue	Vivid Blue-Green
	Ultramarine	Greenish-Blue
	Violet	Ultramarine
	Pink	Paler and more Blue
	White	Blue-Green
	Black	Light Blue-Green
Blue-Green	Red	Abnormally saturated and less Orange (And so on)

After-images are said to be due to two causes. Firstly, to persistence of the visual process after the stimulation has been withdrawn, and secondly to fatigue. The latter phenomenon is of great importance in the technical refinement of the colour film. By prolonged exposure

to one of the primary colours saturated, and of fair intensity, fatigue can be carried so far that we can experience nearly total colour blindness to light of that colour. After complete fatigue for red has been induced, poppies appear black, vegetation bluish-green, and complexions look as they do when illuminated by the old type mercury vapour light. By the production of a certain amount of fatigue emphasis can be placed on certain parts of the picture. For example, the apparent vividness of some green costumes could be much increased by exposure of the eye to some areas of red or rose just before the greens are to appear, and vice versa. The same effect is obtainable with any other pair of approximate complementaries.

COLOUR FATIGUE

This is generally stated to be the cause of negative after-images. Whatever the explanation may be, psychological or physiological, or both, whether retinal in its origin or cortical, matters not; we are concerned primarily with the fact that the sensation commences to alter both in intensity and quality from the moment the vision is fixed upon some part of the visual field. The effect is that the apparatus responds more and more feebly to light impulses of the wavelength of the stimulus, until finally, under conditions of extreme intensity, it will no longer respond at all. We are temporarily blinded.

Abney [1] exposed one eye to red of 0.670μ . He then found that the pure spectrum hues could be matched to another wavelength judged by the other eye (Table 65).

TABLE 65 (ABNEY)

<i>Fatigued Eye observed.</i>				<i>Unfatigued Eye Match.</i>			
(μ)				(μ)			
0.652	..	..	Red	Unchanged			
0.633	..	..	Scarlet	0.611	..	..	Orange
0.610	..	..	Orange	0.587	..	..	Yellow-Orange
0.590	..	..	Yellow-Orange	0.522	..	..	Green Blue-Green
0.572	..	..	Yellow-Y.-Green	0.500	..	..	Blue-Green
0.557	..	..	Yellow-Green	0.492	..	..	Blue Blue-Green
0.541	..	..	Green	0.499	..	..	Blue-Green
0.527	..	..	Green Blue-Green	0.500	..	..	"
0.517	..	..	Blue-Green	0.492	..	..	Blue Blue-Green
0.492	..	..	Blue Blue-Green	Unchanged			
0.482	..	..	Blue	0.486	..	..	Blue
0.474	..	..	Sapphire	0.485	..	..	"
0.465	..	..	Blue-Violet	0.482	..	..	"
0.441	..	..	Violet	0.451	..	..	Blue-Violet

THE PHENOMENA OF COLOUR VISION

Dr. Burch (2) found " that after fatigue for *red*, scarlet geraniums appear black, calceolarias and sunflowers various shades of green, and marigolds green, shaded with black in the parts that are orange to the normal eye. Purple flowers, such as candytuft and clematis, look violet, and pink roses bright sky-blue. Short exposures—a few seconds to two or three minutes—suffice, and the effect is transient, passing off in about ten minutes. After fatigue for violet, violet wools look black, purple flowers crimson, some blues greenish, green a richer hue. A noticeable effect is the tinging of all objects which do not reflect violet with that colour. Fatiguing with green makes the landscape look like a picture painted with vermilion, ultramarine and white. The foliage is reddish-grey or bluish-grey, blue flowers are dirty blue, red flowers are impure red, and every colour but green is tinged with green. Fatigue of one eye with purple and the other with green produced a " very weird and exaggerated stereoscopic effect."

These effects have some bearing upon the colour design of sets in the colour film, but they must constantly be borne in mind in sequences. Consider the case of a momentary glimpse of an exterior following an interior, the prevailing hue in which, let us say, is orange, then the eye, being adjusted for the warm part of the spectrum, will see the colours of the exterior minus red, orange, and yellow. It would appear much too blue—too cold and lifeless. This effect is often visible in actual experience in the street when one emerges from a restaurant illuminated with warm artificial lighting: the exterior looks freezingly cold, and a few moments have to elapse before the

TABLE 66.—APPEARANCE OF SPECTRUM FATIGUED BY LIGHT
OF 0.517μ (GREEN)

Unfatigued Spectrum Colours.		Appearance.
(μ)		
0.652	Red	Bluer and darker
0.633	Scarlet	Redder than unfatigued colour
0.610	Orange	" " " "
0.590	Yellow-Orange	" " " "
0.572	Yellow Y.-Green	Pinkish Orange
0.557	Yellow-Green	Pale Blue-Pink
0.541	Green	Dirty White
0.527	Green Blue-Green	" " " "
0.517	Blue-Green	White, slightly Blue
0.510	Greenish Blue	" " " "
0.492	Blue	" " " " Bluer
0.474	Darker Blue	Pale Blue
0.456	Blue-Violet	Pale Violet
0.441	Violet	Dark Purple
0.429	"	Very Dark Purple
0.415	"	A rather Pale Purple

eye can adapt itself to the new light. In the film it would be necessary to grade the printing of the exterior in the instance referred to such that it was warmer than might be correct in other conditions. The opposite would be true if a warm interior followed a long exterior shot.

Again, we should have to take into consideration the effect upon complexions and flesh colour if the observer's eye had been fatigued by exposure for some time to a warm colour. Suppose we have been gazing at a red door which is suddenly opened, then the complexion of the person entering will seem to be pale and wan. But this, unfortunately, is an instance in which little can be done, except perhaps to place an orange filter over one of the spotlamps illuminating the face. As the person moves through the door this light could be slowly reduced in volume and by adaptation we would soon recover our normal sense of flesh colour.

The advantage of colour-compensating illumination is doubtful, except in a short shot, because the eye quickly adapts itself to a new colour balance and fatigue begins for the second stimulus, while recovery begins in response-power to the primary stimulus. It is impracticable to arrange for a gradual compensation starting at the junction of two contrasting shots. The *mix* permits a brief recovery period and helps to reduce the distortion of colour fatigue and the *fade* is still more effective. The period of a fade in colour should be longer than in black-and-white, as this will give the eye time to recover its neutral balance.

SIMULTANEOUS CONTRAST

There is a reciprocal interaction between contiguous, or nearly contiguous, areas in the visual field. Chevreul called this "simultaneous contrast"; it has also been called "spatial induction." Not only does every colour stimulus affect the response to the stimulus which follows, by means of what has been called successive contrast, or fatigue, but we also find that every stimulated area of the retina has some effect upon the characteristic response of the neighbouring areas. The response of the retinal apparatus depends upon the state of the surrounding area, and the stimulated area itself has some effect upon the surround.

When two different colours are juxtaposed, they modify each other both in brightness and in hue. A patch of grey on a white background looks darker than when seen against a black background.

The contrast effect is greatest at the edges. This can be seen in any pattern consisting of dark and light stripes; the light stripe seems to be graduated in lightness. A photographic wedge of steps of increasing density exhibits this phenomenon at the juxtaposed edges of each step. Separation of the contrasting colours by black much reduces the effect.

The most important characteristic for us to remember is that the surrounding area tends to be modified in the direction of the complementary of the stimulus. The effect is most marked when one of the two colours is white. The white may become apparently quite a saturated hue, indeed, to an extent which constitutes this phenomenon one of the major visual illusions. This effect has been used by painters for centuries; Leonardo de Vinci, for instance, describes it in detail. If it is desired to increase the apparent vividness of a hue such as red, then this may be accomplished by placing its complementary, bluish-green, in juxtaposition to it.

When a white spot is seen against a surrounding area of a pure hue it appears to be a pale colour approximately, but not exactly, the complementary of the background. Abney gives a table (Table 67) which describes the reciprocal modification of pairs of saturated hues.

Another very interesting table of considerable importance to the colourist gives the effect of the spectrum hues when contrasted with white: in each case it was found that the contrast white could be matched by a pure hue plus a certain percentage of white. That the contrast "whites" are not of a hue exactly complementary to the spectrum colours is evident if reference is made to Table 69 of true complementaries.

Note that, according to Abney, the contrast white, to green of 0.558μ , is a whitish orange of 0.610μ dominant wavelength. This is very doubtful, as we should expect the contrast white to be pinkish, the complementary of 0.558μ being a purple.

TABLE 67 (ABNEY)

			<i>Juxtaposed Original Colours.</i>	<i>Effect of the Juxtaposition.</i>	
Red ..	..	Orange	Red becomes Yellower	Orange becomes Green-Grey.
„ ..	..	Green	Red unaltered but brighter	Green unaltered but brighter.
„ ..	..	Blue	Red becomes more Orange	Blue becomes Greener.
„ ..	..	Violet	Red becomes Orange	Violet, no marked change.
Green	..	Orange	Green becomes Bluier	Orange becomes Yellower.	
„	..	Blue	Green becomes Olive	Blue becomes more Violet.	
„	..	Violet	Green becomes Yellower	Violet becomes Bluier.	
Orange	..	Blue	Orange becomes Redder	Blue becomes deeper.	
„	..	Violet	Orange becomes Greener	Violet becomes Bluier.	
Violet	..	Blue	No marked change takes place in either.		

COLOUR CINEMATOGRAPHY

TABLE 68 (ABNEY)

<i>Colour contrasted with White.</i>			<i>Appearance of Juxtaposed White. Colour produced by Contrast.</i>		
<i>Hue.</i>	<i>Wave-length.</i>		<i>Hue.</i>	<i>Dominant Wave-length.</i>	<i>Percentage of White.</i>
	(μ)			(μ)	(μ)
Red	0.672	{	Blue	0.483	0.054
	0.636			0.484	0.057
Orange	0.612			0.485	0.066
	0.598			0.487	0.070
Yellow	0.585	{	Orange	0.481	0.100
	0.569			0.471	0.120
	0.558			0.610	0.165
Green	0.541			0.598	0.165
	0.517	{	Yellow-Orange ..	0.592	0.170
	0.499			0.587	0.175
Blue	0.481			0.585	0.200
	0.466			0.583	0.250
Violet	All violet		Yellow	0.581	0.300

TABLE 69.—LIST OF COMPLEMENTARY WAVELENGTHS FOR ILLUMINANT C

<i>Wave-length (Mμ).</i>	<i>Complementary (Mμ).</i>	<i>Wave-length (Mμ).</i>	<i>Complementary (Mμ).</i>	<i>Wave-length (Mμ).</i>	<i>Complementary (Mμ).</i>
380	557.0	489	600.9	590	485.9
400	667.1	490	607.0	591	486.3
420	567.3	491	616.8	592	486.7
430	567.5	492	640.2	593	487.0
440	568.0			594	487.3
450	568.9	568	439.3	595	487.6
455	569.6	569	450.7	596	487.9
460	570.4	570	457.9	597	488.1
465	571.5	571	463.1	598	488.4
470	573.1	572	466.8	599	488.6
471	573.6	573	469.7	600	488.8
472	574.0	574	471.9	605	489.7
473	574.5	575	473.8	610	490.4
474	575.1	576	475.4	615	490.9
475	575.7	577	476.7	620	491.2
476	576.4	578	478.0	625	491.5
477	577.2	579	479.0	630	491.7
478	578.0	580	480.0	640	492.0
479	579.0	581	480.8	650	492.0
480	580.0	582	481.6	660	492.2
481	581.2	583	482.3	670	492.3
482	582.6	584	482.9	680	492.4
483	584.1	585	483.5	690	492.4
484	585.8	586	484.1	700	492.4
485	587.8	587	484.6	780	492.4
486	590.2	588	485.1		
487	593.0	589	485.5		
488	596.5				

The future art directors of the colour film will have to bear in mind the following facts:

1. The contrast effect is not uniform over the whole surface, but is most marked at the edges.
2. Actual contiguity of the reacting surfaces is not essential for the contrast effect to become apparent.
3. The extent of the background, as well as its lightness and hue, modifies the saturation and lightness of the contrast colour.
4. A narrow black line between the fields diminishes the contrast.
5. With black or white grounds the contrast increases with the saturation of the coloured field.
6. The induced colour sensation is not the precise complementary of the inducing.

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- (5) HARDY, A. C., *Handbook of Colorimetry*, Technology Press, Cambridge, Mass., U.S.A., 1936.
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VISUAL DATA

<i>Visual Function.</i>	<i>Characteristic.</i>	<i>Data.</i>	<i>Authority.</i>
Visibility	<p>Least perceptible quantity of energy.</p> <p>Minimum quanta of radiation.</p> <p>Summation.</p> <p>Threshold visibility and area under dark adaptation.</p> <p>Effect of intensity level of adaptation upon threshold.</p>	<p>$4.2 + 10^{-9}$ erg. per second $2.7 + 10^{-13}$ lumens or $7.3 + 10^{-9}$ candle 1 metre from the eye assuming a natural pupil.</p> <p>54 to 148 quanta measured outside the eye. 5 to 14 quanta in the retinal rods. Green light of $510 \text{ M}\mu$.</p> <p>If two or more similar patches of light are sufficiently close together in a dark field of view they are visible at a lower brightness than a single patch. If the patches are small, say 0.1 in. diameter, and contained in an area of about 1 in. diameter, the threshold brightness for ten patches is about one-tenth that for one.</p> <p>A square whose sides subtend an angle of 2° at the eye must have a brightness of $\frac{1}{1,000,000}$ ft.-lambert.</p> <p>When plotted on logarithmic scale, threshold is proportional to adaptation intensity. If latter is 10 ft.-lamberts, then 0.033 would be undetectable. Fraction of original intensity decreases as level rises. Minimum at 100 ft.-lamberts.</p> <p>Termed "brightness of black." If the eyes are again exposed to a field brightness of 10 ft.-lamberts, then any point in the visual field whose brightness is not over 0.08 ft.-lambert will appear black.</p> <p>"The just appreciable increase of stimulus bears a constant ratio to the original stimulus."</p> <p>"The sensation varies as the logarithm of the stimulus."</p> <p>Sensitivity fraction varies with intensity. High sensitivity between 3.2 and 13.2 ft.-lamberts.</p>	<p>Troland.</p> <p>Hecht, Schlaer, and Pirienne.</p> <p>Meetham and Lambert (1942).</p> <p>Nutting, Blanchard, Reeves.</p> <p>Lowry.</p> <p>Weber.</p> <p>Fechner.</p> <p>Aubert.</p>
Contrast sensibility	<p>Extinction point for light with the eye adapted to a variety of brightnesses.</p> <p>Relation between physical stimuli and sensation.</p> <p>Deviation from law.</p>		

Visual acuity . .	Maximum sensitivity 16 ft.-lamberts. Average of 14 values computed and lower limit of Fechner law given as 5.6 ft.-lamberts. Best region for sensitivity stated to be 10 ft.-lamberts. 10 to 100 ft.-lamberts. Within this range the fractional difference is approximately $\frac{1}{100}$ of the adapting brightness. The smaller the spot the higher must be the intensity for maximum sensitivity. $B = 1\sqrt{d}$, where B is the percentage difference in brightness just distinguishable, and d is the angular diameter of the retinal image. The maximum sensitivity is when the visual angle is not less than 4.2 minutes. Brightness contrasts between 1 and 0.1 (central) surrounding field caused rapid decrease of retinal sensitivity when central field subtended less than 30° at the eye. Decrease small when contrasts were 1 and 10 in opposite direction. Surround brighter than test field, more detrimental than a darker one. When brightness between surround and central field is least the discrimination is best. Reciprocal of such angular size is taken as measure of acuity.	König and Brodhuu, recalculated by Nutting. Troland. Luckiesh. Lowry. Reeves. French. Cobb. Mayer, etc.
Maximum sensitivity range. Effect of area of stimulus. Effect of area of stimulus. Effect of brightness of surrounding field upon discrimination threshold.	Law logarithmic over a range of 0.0000025 to 53.2 ft.-lamberts. No increase up to 4,320 ft.-lamberts. Between 8 and 43 ft.-lamberts 31% increase of acuity. Logarithmic relation between acuity and brightness for a range of from 0.0013 to 20 ft.-lamberts. Little increase in acuity above 4 ft.-lamberts, although some increase even at 20 ft.-lamberts. Value of 5.2 ft.-lamberts given as average beyond which increases of brightness do not yield appreciable gain in acuity.	König. Cobb and Geissler. Ferre and Rand. Troland.
Disappearance of brightness difference because of smallness of pattern.		

<i>Visual Function.</i>	<i>Characteristic.</i>	<i>Data.</i>	<i>Authority.</i>
	Effect of contrast.	Discrimination of form is very noticeably affected by the degree of contrast between the object and its background. Thus at an illumination of 4 ft.-candles, with a contrast of 15%, the acuity was 90% higher than for a contrast of 0.	Cobb and Moss.
	Interrelation.	Within the limits of 1 to 100 ft.-lamberts, visual angle 0.8 to 16 minutes, and exposure times of 0.075 to 0.300 second; brightness level, contrast which includes glare, visual angle and exposure time are naturally complementary. That is to say, a deficiency in one may be compensated for by an increase in one of the others.	
	Size of object and necessary contrast for visibility.	For a given size of test object, necessary contrast for visibility decreases as the brightness level increases. For visual angle of 2.5 minutes a contrast of 5% is required for visibility with a brightness of 92.9 ft.-lamberts and 20% at 0.93 ft.-lamberts.	Luckiesh and Moss.
	Contrast between test object and background (low background luminosity).	Both foveal and parafoveal acuity bear a linear relation to the logarithm of the background luminosity, and contrast is a decided factor.	Conner and Gaunoung.
	Acuity and intensity.	Function increases continuously with increasing background luminosity for the brightness range covered (0.00013 to 1.0 lumen per sq. ft.). For brightness range of 0.4 to 80 ft.-lamberts, increases of 112 to 160% have been registered for normal and presbyopic (tired) eyes.	Ferree and Rand.
Glare	As a component of contrast.	For young eyes increases of acuity not pronounced above 8 ft.-lamberts. With advancing age increases are registered up to 80 ft.-lamberts.	Nutting.
	As a function of intrinsic brightness.	Reduces acuity. Analysed on basis of unpleasantness, shows <i>glare point</i> proportional to cube root of brightness to which the eye is adapted. Discomfort is a function of intrinsic brightness as well as intensity of illumination at the eye.	Cobb and Moss.

Speed of vision	Visual efficiency based on reaction time and absolute brightness.	Following a review of available data, placed at field brightnesses of between 1 and 2 ft.-lamberts provided task was above threshold.	Johnson.
Persistence of vision	— Critical flicker frequency and absolute intensity. And pattern.	Intermittent illumination yields luminous impression which is determined by average energy incident. The rate of alternation at which flicker disappears is proportional to the logarithm of the intensity. Confusion patterns in test field demonstrate that persistence breaks down under certain conditions, increased intensity providing no gain in sensibility. Visual efficiency improved up to brightnesses of 32 ft.-lamberts. Increase of 15% for illuminations between 4 and 16 ft.-candles. (Black type on white paper.) Black type on grey paper having 22% reflection factor gave 50% increase for same brightness range. Progressive increase in motion acuity up to 8.8 ft.-la mberts.	Talbot. Ferry, Porter, Ives. Cobb. Luckiesh.
Speed of reading	—		Basler.
Perception of motion	Space discrimination and changes in the intensity of stimulation at given points on the retina.		Israel.
Accommodation Convergence Fixation	Requisite. Luminosity for efficient functioning.	Average error in accommodation was $\frac{1}{23}$ of the total distance for a brightness of 0.00936 ft.-lambert, and that for both convergence and accommodation was about $\frac{1}{58}$ of the distance. Although accommodation breaks down at very low intensities, both convergence and fixation continue to the absolute threshold (7.3 + 10 ⁻¹⁰ candle, 1 ft. from the eye). Threshold found to be about 0.0024 ft.-lambert. Pupil continues to contract up to brightnesses of at least 1,000 ft.-lamberts, the extremes being from 8 to 2 mm. With illumination at the eye kept at 10 ft.-candles, the pupil area increased by from 20 to 30% for a brightness change of from 37 to 12,077 ft.-lamberts.	Engelking. Reeves. Luckiesh and Moss.
Contraction of pupil	Area and brightness of field varied but illumination at the eye kept constant.	Measurements made of the pupillary light reflex place the minimum of pupil area to be reached for a field brightness of 465 ft.-lamberts and a 17° field. Fixation at the centre of bright field amid dark surroundings.	

WHATEVER principles of colour harmony may have been defined in the past, the theories of writers from Chevreul to Ostwald can have only limited application to a visual art of continuous motion. The relative area occupied by each component tone of a combination (*e.g.*, by each note of a chord) in the case of a static art is of the utmost importance. In the motion picture a relationship which might be theoretically admirable at one moment might be destroyed, if it did not become actively disagreeable at another moment immediately after, owing to a considerable readjustment of the relative areas occupied by the constituent tones as a result of a movement of masses relative to each other. This is a rather academic way of saying that a dress might be very pretty seen against a certain part of a background if fixed there as in a painting, but that its colour might clash with some other part of the background if its wearer moved in front of it, although the tone of this second part of the background was part of an original harmony in the first position.

The most stimulating "laws" which have so far been proposed concerning the *area* of individual tones in a composition are thus formulated:

1. The area of a given colour should be inversely proportional to the saturation of the colour, so that the greater the degree of saturation the smaller the area.
2. The area of a given colour with relation to its hue should be such that the relative area will be greater broadly proportional to the diminution of the wavelength. (Less for the long wavelength end of the spectrum and more for the short wave end.)
3. The area of a colour should be inversely proportional to its lightness, so that the greater the lightness the smaller should be the area.

Since all three variables are often present in combinations of any degree of complexity, it may be said that the first law is the most important one to conform to, and that it provides the governing factor. It follows that if saturated colours are used as a means of creating centres of interest upon which the visual attention is focused, back-

grounds should be relatively desaturated, such that the percentage of the dilution with white should be approximately proportional to the area of the background as compared with the contrasting centre of interest.

Some writers on colour harmony have based their theory of harmony upon the proposition that the respective elements of a combination should constitute neutral grey if their stimuli were additively mixed. This necessitates the assumption that the areas should be so adjusted that neutrality is the outcome of their addition. However, the history of colour harmony gives little if any support for this theory, for in the vast majority of acknowledged examples of good colour the harmonies are of the type in which one tone is predominant, or else there is a general tendency to warm (*e.g.*, the long wave end of the spectrum) colour. If we could make a tremendous patchwork quilt of every picture in the National Gallery, and then by some means additively mix all the separate patches, the combined tone would be a warm grey, but by no means would it comprise a neutral grey. Their canvases curiously lacking in the colours of the short wave end of the spectrum, we might be led to suppose that most of the great painters were in the two-colour stage of visual evolution. It is hard to account for the almost total absence of blue-violet and violet in the works of so many artists by an aversion to these colours. As for Rembrandt, there is not much doubt but that he was either a dichromat or perhaps even a monochromat, that rarest of all the types of colour deficiency, it being improbable that he could perceive blue at all; nor much green either, judging by the absence of this colour from his paintings.

Colour harmony is, when it becomes significant, a product of creative imagination; and as such it is not subject to mathematical analysis. The colour harmonies of a great painter seem to possess the power of inducing responses from chords, so to speak, which lie deep within our natures, and which are but rarely stirred. How does this occur? Presumably deep-lying cultural association response-chains are set in motion. By what process of education does one learn to respond emotionally to the colouring of sunsets, and in the colouring of paintings to the light that never was on land or sea? It is all very mysterious!

From a scientific point of view it is possible to lay down certain generalizations which have a guidance value. For instance, it is true that one of the principal pleasures to be derived from colour depends upon the balances to be effected between dissimilar colour sensations. As soon as two different colour areas are juxtaposed we bring about the phenomenon of contrast. The two sensations may seem either to conflict with each other or more or less to balance each other. We know that the two sensations can differ in three ways: in hue, in saturation, in lightness. It seems that *one of the conditions of balance, and there-*

fore of harmony, is that the two stimuli should have equal stimulus value, but the maximum of difference. The sensations of hue are psychologically a closed series, and the chromaticity diagram in its various forms, as a presentation of the facts of colour vision, is entirely unsuitable as an expression of the psychological aspect of colour vision. Writers like Ostwald have chosen a circular figure for the hue series, and on such a circular diagram those hues will possess maximum difference which lie at opposite points on the circumference. Most of the writers on colour harmony have used the spherical colour solid as the basis of their systems. Such a circular series of hues is easily divided into equal divisions of sensation difference, and by dividing the colour circle into various points an equal number of degrees apart it is possible to form combinations of two, three, and four, or more, tones. Such combinations have been termed dyads, triads, and so on. Many of these intervals, and chords, to borrow the terminology of music, are well-recognized harmonies in the history of the graphic arts (Tables 70-74).

Parry Moon and D. E. Spencer have formulated a geometrical colour construction as a basis for the study of colour harmony. Their foundation consists of a re-presentation of the C.I.E. data (O.S.A. smoothed data) of the Munsell colours which they call the "Metric Colorspace." This is a cylindrical space (known as ω space) in which unit distance corresponds to one Munsell chroma step. They note that the Munsell hues are less equally spaced than the value of chroma steps. Thus Munsell G and BG are too close together, as are R and RP.

Ostwald had laid down that colour harmony was an outcome of orderly (or measured) arrangement. Thus any orderly spacings in the colour solid should provide a harmony. Is colour harmony a branch of geometry therefore? In order to discover the value of this concept one must first have a metric colour space, and this must represent equal sensation differences by equal distances for all three co-ordinates—lightness, hue, and saturation (value, hue, and chroma). Constant visual adaptation to a neutral stimulus corresponding to Munsell value 5 was assumed. The three axes (see Fig. 325) are designated ω^1 , ω^2 , ω^3 . Any colour is indicated by a point P. Lightness differences are measured in a direction parallel to the ω^3 axis. Hue is expressed in terms of angles about the ω^2 axis. In cylindrical co-ordinates (r , θ , z)

$$\begin{aligned} W^1 &= r \cos \theta M \\ W^2 &= z \quad M \\ W^3 &= r \sin \theta M \end{aligned}$$

Any coloured light (C.I.E.) can be specified by (X, Y, Z). These co-ordinates can be transformed to (r , θ , z) and the colour can be represented by a point in ω space. Usually the Munsell notation is employed.

FOR THE CONVENIENCE OF STUDENTS A LIST IS HERE
APPENDED OF WELL-KNOWN DYADS AND TRIADS

TABLE 70

DYADS

Red	..	..	..	..	..	Blue Green
Red-Orange	..	..	..	..	..	Blue
Orange	..	..	..	..	..	Blue-Violet
Yellow-Orange	..	..	..	..	..	Violet
Yellow	..	..	..	..	..	Red-Violet
Red	..	..	..	..	..	Yellow-Green
Red-Orange	..	..	..	..	..	Green
Orange	..	..	..	..	..	Blue-Green
Blue	..	..	..	..	..	Yellow-Orange
Blue-Violet	..	..	..	..	..	Yellow
Violet	..	..	..	..	..	Yellow-Green
Red-Violet	..	..	..	..	..	Green

THE FOLLOWING DYADS ARE LESS PLEASANT BUT
ARE FREQUENTLY EMPLOYED WHEN A RATHER
VITAL EFFECT IS DESIRED

TABLE 71

Red	..	..	..	..	..	Yellow
Red-Orange	..	..	..	..	..	Yellow-Green
Orange	..	..	..	..	..	Green
Yellow-Orange	..	..	..	..	..	Blue-Green
Yellow	..	..	..	..	..	Blue
Yellow-Green	..	..	..	..	..	Blue-Violet
Green	..	..	..	..	..	Violet
Blue-Green	..	..	..	..	..	Red-Violet
Blue	..	..	..	..	..	Red
Blue-Violet	..	..	..	..	..	Red-Orange
Violet	..	..	..	..	..	Orange
Red-Violet	..	..	..	..	..	Yellow-Orange

THESE DYADS ARE SADDER AND RICHER

TABLE 72

Red	..	..	..	..	..	Yellow-Orange
Red-Orange	..	..	..	..	..	Yellow
Orange	..	..	..	..	..	Yellow-Green
Yellow-Orange	..	..	..	..	..	Green
Yellow	..	..	..	..	..	Blue-Green
Yellow-Green	..	..	..	..	..	Blue
Green	..	..	..	..	..	Blue-Violet
Blue-Green	..	..	..	..	..	Violet
Blue	..	..	..	..	..	Red-Violet
Blue-Violet	..	..	..	..	..	Red
Violet	..	..	..	..	..	Red-Orange
Red-Violet	..	..	..	..	..	Orange

THESE TRIADS ARE CHEERFUL AND NOT UNLIKE THE
MAJOR CHORDS OF MUSIC IN THEIR EMOTIONAL
EFFECT

TABLE 73

Red	Yellow	Blue
Yellow	Blue	Red
Blue-Green	Red-Violet	Yellow-Orange
Red-Orange	Yellow-Green	Blue-Violet
Yellow-Green	Blue-Violet	Red-Orange
Blue	Red	Yellow
Orange	Green	Violet
Green	Violet	Orange
Blue-Violet	Red-Orange	Yellow-Green
Yellow-Orange	Blue-Green	Red-Violet
Blue-Green	Red-Violet	Yellow-Orange
Violet	Orange	Green

THE TRIADS IN THIS TABLE ARE SOMEWHAT MORE
SOLEMN AND RICHER IN TEXTURE THAN THE LAST
SERIES

TABLE 74

Red	Yellow	Blue
Yellow-Orange	Blue-Green	Red-Violet
Blue-Green	Red-Violet	Yellow-Orange
Red-Orange	Yellow-Green	Blue-Violet
Yellow	Blue	Red
Blue	Red	Yellow
Orange	Green	Violet
Yellow-Green	Blue-Violet	Red-Orange
Blue-Violet	Red-Orange	Yellow-Green
Yellow-Orange	Blue-Green	Red-Violet
Green	Violet	Orange
Violet	Orange	Green

Western music evolved from the aural recognition of a simple harmonic series of vibratory ratios from which with slight adjustments we can adopt various frequency orders for scales. Some of the scales are generated by simple fractional division of a vibrating string or of the column of air in a tube. What is rigidly fixed for the musician's ear is above all the *interval*, or frequency ratio.

Successive intervals in a regular order form scales, and combinations of intervals form chords the elements of which possess vibratory coincidence, or otherwise, thus providing aural stimuli which are discriminated as more or less pleasant. To-day probably significance is given priority over pleasantness but students must still study "harmony." Vibratory ratios do not permit of doubt, and the degree of

euphony, concordance, or discordance, is not held to be a matter of opinion. In respect of its mathematically defined symbols the musical language is unique. Colour combinations have never been derived from intervals having a physical basis subject to such mathematical orders.

For centuries colours have been used in various combinations in the innumerable manifestations of visual art, and countless theories have been advanced in an attempt to construct systems the application of which would guarantee colouring equal to that of the universally acknowledged masterpieces. The failure of such theories when applied led many to the conclusion that the craftsmen of the great epochs were initiated into some occult secret. Such analysis as has so far been made with the aid of modern physical measuring instruments indicates that no common rules can be discovered to explain the coloration of works as diverse as the windows of Chartres, a Persian rug, or a Chinese vase of one of the best periods. Did these craftsmen obey rules? Was any system ever taught?

The correct reply is probably that apprentices were taught traditional colouring applied to the traditional patterns associated with specialized techniques. Innovations were attempted from time to time as the result of experimentation by an exceptionally imaginative worker and the inventions which met with approval were added to the tradition. In this manner stylistic schools evolved. Such styles were localized geographically and evolution continued often over long periods of time. As the technique of a given craft increased in complexity with an invariable movement towards more elaboration so the colouring exhibits a parallel growth—simple oppositions of marked contrast at the primitive stage—subtle and multiple combinations at the height of power; at the end over-elaboration, over-emphasis, over-richness, vulgarity, ostentation and universal extravagance. We may represent the cycle thus:

TABLE 75

<i>Primitive.</i>	<i>Early.</i>	<i>Middle.</i>	<i>Mature.</i>	<i>Late.</i>	<i>Decline.</i>
Mono-chromatic. Low saturation. Sober but strong	Simple contrasted hue intervals of medium saturation. Effects of increasing vitality	Three or more hues (chords) of high saturation, vigorous and powerful	Compound groups of many hues and covering a wide range of saturation but combined with utmost subtlety. Learned and distinguished	Extremely elaborate combinations exhibiting utmost richness. The period of magnificence	Simpler but over-emphasized and vulgar in effect. High saturation but hue contrasts discordant and "blaring"

Whatever law might be deduced from a scientific analysis of the immense history of applied colour will relate to static patterns, for colour relationships have been conceived by the artist in the past without reference to any extension in time. The motion picture in colour represents the first opportunity for the creation of colour compositions in which the combinations are subject to continuous change, the emotional significance being built up in sequential form, so exploiting the basic principles of music and the drama.

The admonition frequently addressed to cameramen and others concerned with the pictorial aspect of colour films that they should make it their business to study masterpieces of painting is misconceived. The works of the masters, modern or ancient, manifest such a tremendous range of expressive means, and so vast an accumulation of styles, that the student would be left confused and distracted and quite unable to decide what style to emulate, what effects to learn to reproduce, or what harmonies to adopt. No common denominator can be discerned to cover the practice of colourists as far apart as Veronese, Tintoretto, Van Gogh and Derain. Æsthetic principles derived from the contemplation of static works of art will in general be misleading and subject to grave errors when applied to expressive media in which the *form* (viz., *form* in the musical or literary sense) is revealed in a lapse of time. Hence, pictorial composition in the classic sense is no guide to the unfoldment of an idea by form or forms in motion. What may be good static composition at one moment may be bad a moment later, so that the motion picture is not to be conceived as a successful series of *pictures* but rather as an unfoldment of an idea as expressed in terms of visual motion.

If this interpretation be conceded, in what direction are we to look for guidance? Surely, to the ballet and to some extent to the principles of rhythm and gesture which belong properly to dramatic presentation. But in both these art forms the main stresses of shape and of mass in the background have been fixed; accordingly it follows from this limitation that a large area of the visual field has interfered with the condition of unity, which states that if one part moves all parts must eventually move. The holding immovable of a background throughout a poem of movement is to demand of the musical composer that he should hold fast to one bass note until the work be completed. If the background of human rhythmic movement can be caused to take its own part in the action, all its elements in continual fluctuation, a step would have been taken towards a visual art form approaching the perfect æsthetic of music. The realization of this concept can most easily be gained by exploiting the inherent capacities of the motion picture technique. The contribution of mobile colour composition to this end will be of prime importance. Some hints of future possibilities have in this field been given us by Disney.

The retinal field being an *area*, the simultaneous perception of different colours implies division of the area. Division generally results in boundaries, hence shapes and contours, which must bear to one another proportions or ratios of area, and it is the profound influence of this aspect of proportion which has so often been overlooked or wilfully disregarded.

For let there be no mistake, almost any conceivable combination of colours may be made pleasant, or duly expressive, providing the areas allotted to the respective tones be rightly adjusted.

The commonest fallacy is to discuss the harmony of colours as if they were entities always destined to occupy equal areas, as in a pattern of strips equal in width.

Another fallacy easily exposed is implicit in the theory that when unequal areas are allotted to a collection of various colours, providing the integrated light of these (checked by angular section in a rotating disc) is a neutral grey, the condition of harmony will be met. It would not be difficult to show that few, if any, of the acknowledged masterpieces of decorative art would meet this test.

Within the last few years, the systematic classifications of Ostwald and Munsell have supplied a rational basis for theories based upon measured intervals, the root idea being to trace paths, curved or otherwise, in a three dimensional colour structure and to divide these paths into symmetrically spaced intervals, and with further elaboration to oppose a series of spaced intervals complementary thereto, or to contrast them with a corresponding group situated on a path related to the first path by some simple angle. Such paths join the point of a more or less saturated hue lying on the surface of the colour solid with a point on the neutral axis. While this theory cannot be held to explain existing works of art, it is far the most stimulating proposal so far advanced and upon its further development might well be founded the scales, intervals and chords which are sure to constitute the grammar of a future colour language.

For information concerning the older theories the reader is referred to the classic works on the subject, such as those of Chevreul, Rood, Rosenstiehl.

Given the existing state of affairs, the writer feels strongly that little is to be gained by the study of ingenious theories, especially when exposition of these is limited to the use of colour names or to the vaguenesses of colour terminology. What possible sense can be conveyed to the student by stating that "orange harmonizes best with its complementary, blue"? What orange? Which blue? Textbooks of this kind are utterly worthless and still more objectionable are books dealing with the occult and esoteric significance of colour, its spiritual value, its psychological value, its curative value, and any other value you care to imagine.

What can be said of any help as a guide to practice? Only this—that it is usual to ask a musician to direct the music, and that it is equally sensible to ask an artist to direct the colour. Artists, like musicians, are good, bad and indifferent. The wisest course is to choose one held to be good by other artists. Now that film production is attracting (especially in England and the Continent) a culturally higher type there is every prospect of a genuine creative artist being chosen for the job of colour direction, but in Hollywood this would be as unlikely to occur as the choice of Picasso to design the cover of the *Saturday Evening Post*.

The technique of the motion drawing, animated cartoon, or puppet film, gives us the key to the ideal procedure. The artist should prepare a series of compositions in colour, illustrating vital moments of the action, and between these can be inserted further outline drawings indicating important movements of colour masses. When the whole film has thus been set out the next stage is to prepare in complete detail the actual colours of fabrics, colours of each part of a set, of each costume and of every surface in any given scheme. This job should be carried out by a specialist who has at hand complete data as to the known reproduction of every colour in the whole chromatic range as rendered by the colour process being used. This specialist must also have had long experience in the effects realizable by lighting and he must work in close co-operation with the camera staff. The requirement is that the technicians must devote the whole of their skill and knowledge to the realization of the concept of the artist who is primarily responsible for the character of the film as a mobile colour composition. In his turn it is the duty of the artist to interpret the story dynamically and never to lose sight of the fact that the colour treatment has the sole function of emotional and intellectual emphasis, whether this be to impart a heightened sense of reality, to gain an illusion of space, to impart factual information more completely or to induce a mood; these powers of colouring being always held subservient to the fundamental task of better setting forth the drama of the movement of men in their field of action.

There are certain principles which need not be defined for the artist but which should be stated here if only because they have so frequently been disregarded by makers of colour films:—

1. *Simplicity*

The commonest error is *over-elaboration*. Not that an extremely intricate embroidery of colour is incapable of being successfully accomplished, but it enormously magnifies the difficulty of control, and only very rarely can compositions of this kind be brought off with success. We are concerned in the motion picture primarily with following the expressions, gestures and actions of the dramatic characters, and no visual distraction, due to concentration upon incidents, should

be tolerated in either background or surrounding areas. Haphazardly scattered colour incidents are detestable, especially when these have been introduced with the vague idea that the film is in colour and so we must have a vase of flowers here or a cushion there and the more vivid the colour—the better. Keep the whole scheme simple then, and never introduce more colour for the mere sake of colour.

2. *Area and Saturation*

It is a fairly safe rule that the area occupied by a colour should be roughly proportional to its saturation; thus, the larger the area the greyer, the more vivid the colour the smaller the area. But this rule applies more rigidly in the case of the warm hues, purple, red, orange, yellow, than to green, blue and violet, which can occupy large areas without giving rise to unbalance.

3. *Successive Contrast*

Always bear in mind that whatever colour chances to be fixated for even very brief periods will by retinal fatigue leave the illusion of a superposed ghost-image (the after-image) upon any new area upon which the visual centre is turned, and that the colour of the new area will tend to be minus the colour of the area first fixated. The effect will be observable in proportion to the luminosity and to the saturation of the image fixated. This phenomenon is the cause of many disturbing transitions in straight cutting from one shot to another, in which the predominating hue is markedly different. The skill of the colour director is needed to foresee the problems of transition and *colour continuity* with which the editor will be faced. More or less neutrally coloured transitional passages are used for bridging important colour climaxes, and to act as periods of recovery for the retina after violent stimulation. Over and over again one has seen in American musical fantasies this principle flouted, with consequent colour fatigue arising from lavish bouquets of colour piled one on another irrespective of successive contrast, until the more sensitive of the audience mentally cry for mercy.

4. *Subtlety*

“Gorgeously glorious” colour cannot equal the intense pleasure the average individual discovers in a sober, cool and mirror-like palette. We ought to study Vermeer and Velasquez rather than the Baroque Rubens and Titian. It is easier to compose colour massed like the fruit on a market stall than to match the delicacy of a Girtin watercolour. It is grossly untrue to dismiss subtle colouring as wasted upon an apathetic public. Beautiful things have a singularly final way of winning all hearts and all minds, whether they want to be won or no. Let your tones be difficult to describe and difficult to remember.

5. Key

There is a quality in good colour composition for which artists have adopted the musical term *Key*. The difficulty of describing just what this means is due partly to the inadequate explanations offered by artists themselves, who have rarely been competent to analyse their perceptions. Two principles are to be marked—first, a shift of every chromaticity in a direction such as would result from the photography of a colour temperature somewhat lower than that for which the system is balanced. Thus if the recording system is neutrally balanced to an average daylight of colour temperature $6,000^{\circ}$ K., the effect of using a very dilute *daylight to tungsten* filter will result in a just perceptible increase of warmth. The problem here is that in theory a neutral grey scale should now *not* be rendered by the laboratory colour grader neutral to the projection illuminant (the usual procedure) because relative to the appearance of such a grey in an equal energy illuminant, this neutral grey will now be on the “golden” side of neutral. This is precisely what happens if we varnish a painting with a very dilute golden varnish: the whole range of chromaticities is shifted, the shift, however, being greater for the greens, blues and violets, than for the warm colours. The same thing happens when we view an exterior through spectacles tinted, say, very pale flesh colour. This minus filter changes the “key.” If the minus filter is dense enough it will cause an apparent *predominance* of one hue, as when daylight scenes are photographed through a filter designed to render the subject as it would have appeared illuminated by moonlight. “Key” in this sense can be technically defined as—The employment in a composition of a chromaticity area or range with its saturation maximæ markedly inclined towards one part of the spectrum. (Viz., as it would appear if plotted on the C.I.E. chromaticity chart.)

Secondly, there is that necessity of key which relates to the use of a chosen hue as a recurring *motif*, a device which contributes much towards achieving unity, a prerequisite condition of artistic production. This principle must be introduced with discretion if it is not to bore by becoming obvious. For a woman to wear dresses of the same colour throughout the film would be ridiculous, regardless of time, place and circumstance, but by restricting the costumes to the wide range covered by all the modifications of saturation and luminosity of one hue, the desired effect of unity will be obtained. The feeling must be conveyed to the audience that a certain colour is the pivot, or axis, towards which all other tones converge. For this technique the colour director will find a Munsell atlas¹ an invaluable guide. The necessity that the film should possess *continuity* will also be helped by the colour motif. The prevalence of one line will serve as a bridge to link the phases of the film.

¹ “Munsell Book of Color” (Munsell Color Company, Inc., Baltimore, Maryland, U.S.A.).

Colour Standards: Measurement and Specification

THE colour composer of the future will not work without some system of arbitrary reference to definite specifications. No doubt in the early stages of colour film production artists will resort to their lazy, inaccurate methods of indicating their ideas by means of messily executed sketches in gauche or water-colours, but for the colour composition of the future a method for indicating colour tones is required no less accurate than that employed by an engineer when he drafts the steelwork of a skyscraper, because a few rough washes with a water-colour brush of some mixture of pigments familiar to the artist, such as cobalt blue, chrome orange, light red, etc., bear little or no relation to the actual colour which may be finally seen upon the screen, which is the resultant of a large number of intricately related factors which have been examined in the section of this book dealing with the recording and reproduction sequence. Nor is it likely that the coloration of a given part of a film will begin by a rough sketch by a painter which can then be handed over to the technical men for its practical realization. It follows, therefore, that the film colourist of the future will have to possess as part of his training a thorough mastery of all the technical aspects involved in order for him to collaborate intelligently with the specialists controlling each stage of the colour recording and reproduction, whereas, through lack of realization of these requirements, it is certain that in the early stages of colour reproduction painters will be called in to supervise colour direction who, by the nature of their environment and training, are not equipped to understand even the elements of the theory and practice of colour photography.

Although from a purely scientific point of view a colour atlas provides an arbitrary and relatively inaccurate method of specification, instruments such as trichromatic colorimeters or spectrophotometers are expensive and somewhat inconvenient for the purpose, so that it is likely that colour atlases will provide for the time being the most satisfactory method of colour-tone indication. A great number of colour atlases have been devised. A. H. Munsell, an American artist, devised the well-known Munsell System and in 1905 first published

A Color Notation [1]. In 1915 *The Color Atlas* [2] appeared. Today *The Munsell Book of Color* constitutes the most valuable atlas of pigmented samples in existence. The samples are arranged in an order based on sound principles, and this atlas has received wide recognition in the United States as a basis for colour specification. The corresponding German colour system, based on the work of Professor W. Ostwald, a renowned chemist, was first embodied in *Der Farbatlas* published in 1917. This system has also been widely adopted, but its fundamental basis is not in accordance with modern psychological, or psychophysical, teaching, and it is not likely to survive.

Munsell recognized from the inception of his work that the three characteristics which define completely a colour sensation are hue, lightness, and saturation, termed by him hue, value, and chroma respectively. He constructed a cylindrical solid in which the vertical co-ordinate represents lightness (*value*), angle about the axis represents hues, and distance from the axis relative saturation (*chroma*). "The ideal is a psychological colour solid in which cylindrical co-ordinates of Euclidean space represent the principal attributes of colours perceived as belonging to surfaces and equal linear extents represent equal sense-distances. Along the colour scales there is variation in but one attribute at a time and the scalar gradations are perceptually uniform. Furthermore, any horizontal section through the solid would define a plane of constant lightness (Munsell *value*), while any vertical plane originating at the achromatic axis would be a plane of constant hue. Finally, a cylindrical section concentric with the axis would constitute a surface of constant saturation (Munsell *chroma*)" [3].

The Munsell scale units of hue, value, and chroma are not equivalent perceptually. The relation between these units is as follows: One value unit=2 chroma units=3 hue units, (at 5 chroma).

The Munsell notation is as follows:

A number and one or two letters indicate location of the given colour in the hue circuit, which is divided into 100 hue steps. Each of the ten principal Munsell hues (R, YR, Y, GY, G, BG, B, PB, P, RP) may be accompanied by any number from 1 to 10 to indicate the lesser variation or steps in the circuit. The principal hues are understood to fall at positions indicated by the number 5, and it is conventional to omit this number in the hue notation. Any hue with a designation greater than 5 lies farther along the hue series (clockwise direction), while designations less than 5 indicate counter-clockwise departures from the principal hue. Thus 9R is a yellowish red, for it departs from R (or 5R) by four hue steps in the direction of yellow-red (YR). On the other hand, 2R is a somewhat purplish-red because it lies three steps in the counter-clockwise direction toward RP. Numbers ranging from 0 to 10 indicate location on the value scale. Thus

value 1/ indicates a near black, 5/ indicates middle grey and 9/ a near white. The extreme values or ideal limits, 0 and 10, are not realized in practice. Numbers ranging upward towards theoretical limits (23), represent degrees of chroma. Upper limits in practice depend upon the availability of suitable pigments. Zero chroma means an achromatic or grey colour in which hue is absent. In the complete notation of a colour the hue designation is given first, followed by a fractional form of which the numerator is the value designation and the denominator is the chroma designation. Thus, for instance, 7R 3/8 specifies a colour which is predominantly red in hue with a minor yellow component, somewhat low in value and only moderately high in chroma.

A subcommittee of the Colorimetry Committee of the Optical Society of America in 1937 undertook a re-spacing of the Munsell colours with the object of smoothing out the spacing into perceptually uniform colour scales, in accordance with psychological judgments averaged for a large number of observers. In 1940 the data were summarized in the form of averaged visual estimates of the correct notations of the hue, value, and chroma of each sample. Subsequently, in 1943, the subcommittee published a psychophysical system based on the 1940 data which corresponded as closely as possible to an ideal psychological colour solid consonant with practical usefulness. The current samples were re-designated with a revised Munsell notation.

It remains to be seen whether an attempt will be made later to issue a revised atlas in conformity with these investigations and recommendations, but it may be discovered that modifications will perforce have to be made in the Munsell System which might result in its being less adaptable to its acknowledged purpose if it were made to conform to an ideal of perceptual uniformity.

The Munsell Book of Color should be possessed by every technician concerned with the production of motion pictures in colour. It will prove to be as valuable an aid to the photographer as to the colour director, constituting, as it does, a common basis for specification, discussion, and test of the limits of reproduction.

The problem is too vast a subject to receive detailed treatment in this book. For further information the reader is recommended to read the following works:

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COLOUR SCORES

If the Art Director is to be responsible for the colour composition of the film he should present his ideas in the form of a score. There is no other way by which he can give the Director a clear idea of the relation between the colour treatment of the developmental rhythm of the film as a whole. It is probable that the colour score should not be composed until the music has been recorded. First should come the general conception of the sound treatment, and afterwards the composition of the light. The score should take the form of a loose-leaf book consisting of a page to each scene mentioned in the shooting script. Each page will represent in the form of vertical bands the principal colours to be used in the scene. The width of each band should be related to its probable area in the final picture. At the top of each band should be given the code number of that particular colour in the colour atlas which has been adopted as standard in the production organization. No better atlas is available than the Munsell charts, and we can assume that this atlas will be used for the purpose. On turning over the pages of the score one can see at a glance the sequential dynamic of the film, and the colour harmonies should have direct psychological relationship to the film fluxion and to the musical treatment. A useful suggestion is to paint the subordinate colour elements, and perhaps also the principal costume harmonies on celluloid sheets, so that these can be seen superposed on the colour schemes of the backgrounds, which should have been painted on opaque paper. In this way several different costumes can be observed in relation

to one background. The painting of these colour scores should be done by an apprentice textile designer from atlas indications noted down by the Art Director, who can work quite efficiently without resorting to painting at all. Such young draughtsmen are available in Manchester, many of whom would, no doubt, be inclined to enter the artistic side of the motion-picture industry. These draughtsmen have received special training in laying down smooth tones in solid water-colour. Their skill is far beyond that of the average professional artist, and the accuracy of their work has to be seen to be believed. Thus the Art Director would be relieved of the drudgery of painting scores, and he would be free to concentrate his powers on invention.

Needless to say, it will be necessary for everyone who is concerned with colouring to have a copy of the colour atlas. The atlas should be kept by, amongst others, the Make-Up Artist, the Wardrobe Mistress, the Dress Designer, and the Set Dresser. The production staff must accustom themselves to the correct designation of colours in their conversation. "A nice warm grey" or "A sort of bluey-green" mean nothing to the colour expert, and not so very much to the artist. When the colour score system has been adopted, a given colour tone can have one, and only one, description; and there is no more doubt about its meaning than there can be as to the significance of the notation in a musical score.

THE FUTURE OF THE COLOUR FILM

On re-reading this section of the last edition of this book (in 1939) the author is impressed with the accuracy of many of the predictions then made. It is a fitting moment to review the former material and to make such comments as may be apposite under the present altered condition of the world.

The question was put: "Will the colour film altogether supplant the black-and-white film?" Not one word of the reply need be altered. This was the answer: "It is extremely unlikely that we are about to witness a rapid change-over in picture-making in any way comparable to that which occurred when sound reproduction became available. This statement is made in spite of the daily repeated prophecy that we are in for a revolution in the industry. On the contrary, it is much more likely that the proportion of colour films to black-and-white will gradually, and very gradually, rise during the next five years. It would be very surprising to the writer if in five years from now *one-half of films are made in colour*." Now the position is that probably not more than one-tenth are made in colour today in 1949, and it will still be surprising to the writer if one-half of all films are made in colour in the year 2000. The reply continues: "Not the least reason for think-

ing this, is the cost of negative and positive film stock for colour as compared with black-and-white. Unless remarkable economies can be effected on some other important item of the cost of making a film, it is difficult to see how the extra cost of negative and positive is going to be borne by the producers; especially as it is universally admitted that it is going to be impossible to make more out of a film just because it happens to be in colour, for the very simple reason that the public will not pay more to see it. Naturally, we are justified, in some degree, in hoping that ultimately the cost of negative and positive will perhaps be only a fraction more than black-and-white. There is little evidence that this is likely to be the position for some time to come, however." The truth is that the prospect of cheaper colour stock is as distant as ever, if indeed it has not retreated beyond the horizon altogether.

After pointing out that the standard of laboratory processing would have to be higher than for black-and-white, it was stated that: "It is probable that colour printing will remain, for some years to come, the prerogative of laboratories, not only possessing the most up-to-date equipment, but which have the advantage of a specially trained staff who are familiar with the peculiar problems involved in balancing three-colour printing." This is still true.

Nothing has since occurred to upset the validity of the following: "To those of us who have had some years' experience of colour films it is a remarkable fact that the introduction of colour into the picture seems to arouse instant criticism from an audience which will tolerate normally any amount of distortion in black-and-white. It would seem as if the normal power of colour identification is very highly developed. By this is not meant that the average individual in Europe or America—certainly not the average male—has a highly developed colour memory, but that any slight distortion from the condition of neutral balance is very quickly spotted as *unnatural*. And we have to recognize that if the colour process was *perfect* within the illumination limits of projection, the condition of an *illusion* would very nearly have been obtained, the third dimension being the only missing factor. Owing to this developed sensitivity to balance, and probably to range of hue, the audience has hitherto come to regard colour films as being obviously in the experimental stage; and this conviction has built up a considerable antagonism, which it will take a long time to break down. Two-colour films no doubt did an immense deal of harm, and still do so. People learn to expect gross distortions—in fact, all the old history of red trees and sunburnt complexions. It is remarkable how men who have spent a large part of their lives in pioneering colour processes have retained their ability to observe faulty colour reproduction in other processes, but long familiarity with their own process has blinded them to its imperfections; and sometimes to such a degree that they

are prepared to swear that brown is green and grey is violet. They are like men in love, who cannot conceive that others may see obvious faults in the supposedly perfect person, or their processes are like old friends of whose defects they have long ceased to be aware." How true this still is! And how amazing that two-colour processes should have been raised from the dead again! And how sad, too!

Nor need the following be retracted: "It can be argued that a certain lack of realism, an element of limitation, or what artists (painters) call *convention*, is a desirable artistic quality, but it is unwise to expect the general cinemagoer to appreciate such æsthetic refinements. For them the criterion of excellence in colour will be its approach to absolute fidelity. As the writer has again and again pointed out, the proper approach to the problem for the maker of the colour film should be, at first anyhow, to place the minimum stress upon the accident of colour as such. The quality of the colouring should be such as hardly ever to call attention to itself. The first colour film to be received with universal acclamation will be that one in which we shall never have been conscious of the colour as an achievement. The inclusion of colour will have given us a sensation of well-being, a general feeling of greater completeness. At present, of course, directors are like children who have been given a new toy, and are not quite sure how it is supposed to work, nor quite what it is intended for."

Even the sponsors of Technicolor are prepared to admit that it is a pity that things so turned out that this process gained a virtual monopoly of the field. It would have been a vastly more healthy state of affairs, especially in the early stages of the evolution of the colour film, for there to have been at least three or four alternative types of product. We can predict with almost absolute certainty that this so long held dominance of Technicolor is coming to an end. We all know that in the public's mind colour films are synonymous with Technicolor. Indeed, Dr. Kalmus and his associates have added adjectives to the language, for do we not frequently read of "technicolored sunsets"?

The general availability of the multilayer type of negative-positive film should result in the increasing use of colour photography for the newsreel. At any rate, the technical limitations which have hitherto restricted its use for this purpose have been largely eliminated, and now there remains only the economic barrier to be surmounted. The price of positive prints might be so high as to require an impossible increase in the cost to the exhibitor in order to provide an adequate return. Whether any increase in the distributor's charges is practicable is open to question. The trouble is that multilayer film is very costly to manufacture owing to the number of coatings and the high percentage of waste. It is indeed doubtful if this class of film could be made either in the United States or in Britain at a sale price equivalent to that at

which the Germans are reported to have sold it during their brief period of production.¹ In any case, Agfa was probably subsidized by the Nazi Government, so that we cannot judge whether the economic conditions of manufacture were in any way normal. The positive stock processed could hardly be sold in Britain at less than sixpence a foot, on the basis of such information as we now possess as to the processes of manufacture and the cost of the raw materials used. At this figure its use would be restricted by the newsreel organizations to films recording events of special interest. That the characteristics of the process lend themselves particularly well to the newsreel has been demonstrated convincingly by films made by the Russians. Obviously the material has latitude approaching that of monochrome, while the speed is adequate to permit very considerable depth of focus. Since over twenty cameras were used for the film of the Sports Parade in Moscow, clearly no more skill was required than it would be reasonable to expect of any newsreel operator.

A study of the attitude today of the British public towards the colour film does not reveal as yet any decided preference for feature colour films. There does seem to be a marked antipathy to excessive use of vivid colour—apparently popular in Hollywood—which may be due to a national liking for the restrained and rather sad tones typical of the British sentiment for colour during the last hundred years. The average cinemagoer is attracted primarily by the individualities of their favourite stars and by the story and treatment, and the question of colour is only a subsidiary factor of final polish. On the other hand, there is not the slightest doubt that the cartoon film is immensely preferred in colour, which is hardly surprising since it is in the animated drawing that colour is discovered to be an expressive factor of major value. Newsreels, documentaries, and educational films, are all preferred in colour.

Had all the sustained efforts of countless men of science, technologists, and financiers to perfect the means of making motion pictures in colour had as their ultimate end the production of ephemeral entertainment for the masses, one might doubt that success was an adequate reward, but luckily the finished tool had work to be put to of more permanent value to man, for the colour film is destined to make a contribution of real value to civilization in education and scientific research. As example we may mention the valuable work which has already been done for medicine and agriculture. Thus the promise of lucrative reward from the exploitation of a technological triumph has not for the first time resulted in benefits being conferred in cases unforeseen by men moved rather by greed than by desire for mastery of material means for the greater public good.

¹ Nevertheless Kodak and Du Pont have since offered colour positive raw stock at 4½ cents a foot.

Man stands at the parting of his way. His technical triumphs offer self-destruction or the enjoyment of a meaningful existence. He must choose. A colour film can be brought to shame by the base misuse of evil propaganda, or a colour film can reveal a secret of nature and so serve the well-being of all men. We who played our part in the fashioning of this tool cannot refuse the challenge. It is for us to choose which way it shall be. Choose then as servants, but not as slaves—for this in truth is the choice before us.

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APPENDIX I

BRITISH PATENTS 450,673-566,346. COMPLETE PATENT LIST CONTAINING EVERY PATENT HAVING SOME BEARING ON COLOUR CINEMATOGRAPHY

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|---------------------------------------|--------------------------------------|
| 450,673. Opt., Brewster. | 456,617. Lenticular. |
| 685. Gaspar. | 818. Screen. |
| 877. Harmonicolor, 2-Col. | 457,326. Col. Dev., (M.L.), I.G. |
| 958. Sensitizers, Kodak. | 476. Opt. |
| 451,175. Lenticular, I.G. | 656. Lenticular Stereo. |
| 347. Sub., I.G. | 843. Opt. Proj. Filter. |
| 699. " M.L., Kodak. | 458,256. Sub., Gaspar. |
| 452,243. Screen, Dufay. | 304. " " |
| 345. Sub., Multilayer. | 400. " (M.L.), I.G. |
| 453,221. Opt., <i>Thomascolor</i> . | 418. Opt. Lenticular. |
| 233. Multilayer, Kodak. | 427. " Bernardi. |
| 674. Sub., Dye Toning. | 428. " " |
| 454,088. " (M.L.), I.G. | 452. " " |
| 163. Lenticular. | 457. " " |
| 357. Opt., Lenticular. | 458. " " |
| 498. Sub., Kodak. | 491. " Proj. C.M.C. Corp. |
| 499. " " | 664. Sub., Kodak. |
| 622. " " | 665. " " |
| 788. " Multilayer, I.G. | 459,027. " Printing, (M.L.), I.G. |
| 842. Lenticular, Bipack, (M.L.), I.G. | 234. " 2-Col., Triggs. |
| 455,128. Sub., Kodak. | 634. Lenticular. |
| 220. Lenticular. | 636. Opt., Brewster. |
| 371. Opt. Proj. | 664. " Prism (Bellingham & Stanley). |
| 556. Col. Former, (M.L.), I.G. | 460,335. Opt., Beam-splitter. |
| 456,279. Yellow Filter, Kodak. | |

ABBREVIATIONS

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|---|--|
| Col. Dev.—Colour Development. | Col. Cor.—Colour correction. |
| M.L.—Multilayer process. | Sep. Layer.—Separating layers. |
| Opt.—Optical synthesis process or exclusively optical subject matter. | Dye Des.—Dye destruction or silver bleach process. |
| Sub.—Subtractive process. | Col. Res.—Colour Research. |
| Screen.—Mosaic screen additive process. | Unclass.—Unclassified. |
| Lenticular.—Lenticular additive process. Embossed film. | I.G.—I.G. Farben Industrie. |
| Misc.—Miscellaneous category. | Diffra.—Diffraction process. |
| Proj.—Projection. | Sensit.—Sensitizer. |
| 2. Col.—Two-colour. | Gel.—Gelatine. |
| Imbib.—Imbibition process. | Mask—Masked. |
| Col. Rend.—Colour Rendition. | Cplrs.—Couplers. |
| | Prot.—Protected. |
| | P.C.C.—Protected Colour Coupler. |

COLOUR CINEMATOGRAPHY

- 460,533. Lenticular.
- 580. Sub., (M.L.), I.G.
- 653. " Lenticular (M.L.), I.G.
- 461,006. " " (M.L.)
- 559. " " "
- 621. Opt. Lenticular.
- 462,140. Sub., Kodak.
- 232. " Allison, 2-3-Col. Toning.
- 655. Opt. Lenticular.
- 794. Lenticular.
- 996. Stereo.
- 464,398. Sub., (M.L.), I.G.
- 723. Lenticular.
- 852. Sub., Gaspar.
- 465,005. " *Truecolor*.
- 090. " "
- 765. " "
- 823. " (M.L.), I.G.
- 466,290. Misc., *Cinecolor*.
- 528. Opt. Beam-splitter.
- 710. Misc., *Truecolor*.
- 467,087. Col. Dev., (M.L.), I.G.
- 110. Sub., " *Omnichrome*."
- 380. Col. Dev., *Truecolor*.
- 614. Sound, Kodak.
- 468,508. Sub., Gaspar.
- 509. " "
- 560. " Kodak.
- 833. Opt. Printing, Moreno.
- 848. Multilayer, I.G.
- 946. Sub., (M.L.), I.G.
- 469,359. Opt. 4-Col. Additive.
- 759. Sub. (M.L.) Steiner.
- 470,074. " Murray.
- 653. Opt. Beam-splitter.
- 801. Lenticular.
- 855. Sub., Spencer.
- 914. " Toning, (M.L.).
- 959. Opt. Lenticular Proj.
- 471,102. " Beam-splitter, Kanturek.
- 297. " Copying, Kampfer.
- 520. Sub., (M.L.), Kodak.
- 586. Screen.
- 472,206. Opt., Kampfer.
- 224. Col. Dev., (M.L.), I.G.
- 468. Opt. Beam-splitter.
- 644. Sub., Gaspar.
- 981. " "
- 473,422. Opt. Lenticular, I.G.
- 725. " Screen.
- 766. " "
- 782. " -Col.
- 993. Sub., " *Cinecolor*."
- 474,353. Col. Dev. Kodak.

- 474,800. Opt. " *Cosmocolor* " Beam-splitter.
- 914. " *Omnichrome*."
- 475,191. Sub., (M.L.), I.G.
- 415. Opt. Prism Beam-splitter.
- 655. Sub., Pollak.
- 784. Multilayer, Kodak.
- 785. " "
- 786. " "
- 808. Opt., *Technicolor*.
- 476,460. Sub., Kampfer.
- 672. " Multilayer, (M.L.), I.G.
- 477,236. Opt. Lenticular, Thomson-Houston.
- 421. Opt. Lenticular.
- 524. Sub., Kodak.
- 829. Opt. Screen Printing.
- 848. Filters.
- 928. Misc.
- 478,058. Opt. Proj.
- 329. Screen.
- 500. Opt., Hillman.
- 501. " "
- 644. " Lenticular.
- 714. " "
- 735. Sub., Gaspar.
- 766. Opt. 4-Col. Proj., Kampfer.
- 933. Col. Dev., Kodak.
- 934. " " "
- 942. " " "
- 945. " " "
- 983. " " "
- 984. " " "
- 985. " " "
- 986. " " "
- 989. " " "
- 990. " " "
- 991. " " "
- 479,752. Col. Cor., (M.L.), I.G.
- 838. " Dev. " "
- 480,123. Lenticular.
- 164. Opt. 2-Col.
- 251. Multilayer, *Truecolor*.
- 287. Sub., *Truecolor*.
- 291. " "
- 487. Opt. Lenticular.
- 766. Screen.
- 778. Sub., (M.L.), I.G.
- 854. " " "
- 481,175. Screen.
- 274. Sub., (M.L.), I.G.
- 275. " Col. Dev., I.G.
- 275. " (M.L.), I.G.
- 336. Opt.

- 481,501. Col. Dev., (M.L.), I.G.
 502. " " "
 702. Sub., (M.L.), "Gevaert."
 953. Opt. Additive Proj.
 482,068. " Lenticular.
 624. " 2-Col.
 652. Multilayer, (M.L.), I.G.
 690. Opt. Lenticular.
 733. Multilayer, (M.L.), I.G.
 483,000. Sub., (M.L.), I.G.
 020. " *Truecolor*.
 035. " "
 079. Opt. Hillman.
 271. Sound, (M.L.), I.G.
 319. Lenticular, Kodak.
 366. Sub. Gaspar.
 463. " "
 366. Sub., (M.L.), Gaspar.
 463. " " "
 464. " " "
 548. " (M.L.), I.G.
 817. Opt., Hillman.
 819. " "
 820. " "
 878. " Lenticular.
 484,096. Misc.
 411. Imbibition, *Technicolor*.
 698. Sub., I.G.
 797. Opt. Lenticular.
 485,190. Sub., Printing.
 552. Printing, Gaspar.
 577. Misc.
 861. Sub., (M.L.), I.G.
 862. Sub., (M.L.), I.G.
 486,005. " (M.L.), "
 043. " " "
 107. Misc. Sub.
 424. Sub., (M.L.), I.G.
 495. " " "
 496. " " "
 517. " " "
 839. Opt.
 848. Sub., (M.L.), I.G.
 916. Opt. Lenticular.
 487,685. " "
 769. Sound, (M.L.), I.G.
 941. Imbibition, I.B. Corp.
 488,048. Sub., (M.L.), I.G.
 070. Opt.
 093. Sub., Gaspar.
 108. Sound.
 398. Opt. Lenticular.
 488. Sub.
 499. Shutter, *Truecolor*.
 548. Sub., (M.L.), I.G.
- 488,555. Sub., (M.L.), I.G.
 650. Gaspar.
 835. Col. Cor.
 853. Sub., (M.L.), I.G.
 489,093. " " "
 161. " " "
 162. " " "
 164. " " "
 185. Misc.
 274. Col. Dev., (M.L.), I.G.
 299. Sub. Col. Dev., Spencer.
 333. Opt., *Cosmocolor*.
 355. " Lenticular.
 517. " (Swiss).
 529. " Lenticular, Kodak.
 701. " 2-Col. (Belgian).
 823. Lenticular.
 845. Sub., (M.L.), I.G.
 490,451. " Gaspar.
 468. Opt.
 516. Multilayer, I.G.
 517. " "
 844. " "
 491,856. Col. Cor., Gaspar.
 958. Sub., (M.L.), I.G.
 959. " " "
 492,518. Col. Dev., (M.L.), I.G.
 523. " Cor., (M.L.), I.G.
 648. " Rend., (M.L.), I.G.
 672. Sub., Gaspar.
 673. Opt., *Technicolor*.
 711. Sound, Gaspar.
 850. Opt. Lenticular.
 493,308. Col. Cor., (M.L.), I.G.
 804. Opt. Lenticular.
 869. Col. Cor., (M.L.), I.G.
 879. " " Philips.
 952. " Dev., Kodak.
 494,144. Sound, (M.L.), I.G.
 333. Opt., Hillman.
 334. " "
 341. Col. Cor.
 456. Opt. Lenticular.
 495,100. Screen Printing, Zeiss.
 135. Opt. Anaglyph. (Italian).
 348. " Lenticular.
 353. Repeating Back.
 821. Opt. (British).
 898. " Screen Proj. (German).
 931. Beam-splitter.
 496,049. Misc., I.G.
 116. " " "
 195. Col. Dev., Kodak.
 245. " " "

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496,463. Col. Dev., Du Pont.
 558. Sub., Gaspar.
 559. " "
 618. Misc., Du Pont.
 753. Opt.
 821. 2-Col. Opt.
 997. Col. Cor.
 497,463. " Dev.
 698. " " Du Pont.
 753. Opt. Lenticular, I.G.
 849. Misc. 2-Colour.
 498,461. Sub., Gaspar.
 663. Col. Rend.
 749. Sub., *Truecolor*.
 762. " "
 869. " (M.L.), Kodak.
 870. " " "
 871. " " "
 874. " " "
 875. " " "
 499,005. Opt. Beam-splitter.
 054. " (Swiss).
 131. Col. Rend., I.G.
 185. Sub., (M.L.), Kodak
 758. " Imbib., I.G.
 500,047. " Veracol.
 098. " Gaspar.
 312. Opt. Lenticular.
 611. Sub., Kodak.
 612. " "
 613. " "
 687. " D. R. White (U.S.A.).
 716. " Kodak.
 717. " "
 718. " "
 719. " "
 720. " "
 721. " (M.L.), Kodak.
 793. " "
 794. " "
 795. " "
 796. " "
 798. " Stock (German).
 826. " Kodak.
 945. " I.G.
 501,000. " (M.L.), Kodak.
 001. " " "
 002. " " "
 003. " " "
 040. Col. Rend., Kodak.
 190. Sub., I.G.
 435. Opt. (Austrian).
 661. Col. Rend., Inter. Chem. Corp.
 812. Opt. Screen, Crisp.
 987. Sub., Dufay-Chromex.

502,960. Col. Dev., Kodak.
 503,077. Sub., I.G.
 222. Opt., Tate & Colortone Corp.
 318. Sub., I.G.
 330. " (M.L.), Gaspar
 379. " " "
 597. Opt.
 752. Sub., Kodak.
 752. Col. Dev., Kodak.
 814. Sub., Kodak (Schinzel).
 822. " "
 823. Col. Dev., Kodak.
 824. Sub., Kodak.
 825. Col. Dev., Kodak.
 827. " " "
 845. " " "
 873. " " "
 939. Sub., (M.L.), Kodak.
 940. Sound.
 941. Sub.
 504,376. " I.G.
 505,027. Col. Rend., I.G.
 099. Sub., *Truecolor*.
 214. Sound.
 282. Opt.
 694. " (Italian).
 834. Sub., Martinez.
 861. " Du Pont.
 506,224. " Gevaert.
 258. Col. Cor., Inter. Chem. Corp.
 259. " " "
 281. Opt. Lenticular.
 331. Sub., I.G.
 359. " "
 450. Filter Layer, *Cinecolor*.
 514. Sound, I.G.
 581. Col. Cor.
 637. " Rend.
 667. Opt. Multiscreen Sease.
 727. " Dunning.
 827. Col. Cor., Inter. Chem. Corp.
 507,009. Sub., I.G.
 152. " Gaspar.
 211. " "
 357. " "
 418. " "
 485. " "
 611. " *Veracol*.
 841. " (M.L.), Kodak.
 508,011. Filter Layer, I.G.
 468. " " "
 802. Col. Rend., I.G.
 509,224. Lenticular.
 269. Opt.
 707. Sub., Kodak.

- 509,918. Sub. Sep. Layer.
 510,523. Sub., Kodak.
 598. Col. Rend., I.G.
 784. " " Kodak.
 884. Sub., Gaspar.
 511,039. " I.G.
 134. Paper (French).
 462. Sub.
 535. " Gevaert.
 574. Col. Rend., I.G.
 690. Sub. Dye Des. (Swiss).
 770. Col. Rend., I.G.
 773.
 790. Sub., I.G.
 800. " Kodak.
 804. Lenticular.
 899. Opt.
 512,060. Col. Dev., I.G.
 542. " " Du Pont.
 559. " " Kodak.
 563. Sub. Sease, (Du Pont).
 608. Col. Rend., Kodak.
 726. Opt. (Italian).
 733. Lenticular.
 752. Col. Dev., Kodak.
 755. " Rend., I.G.
 513,234. Sub. Sep. Layer., I.G.
 244. " Imb., I.G.
 554. Filter Layer, I.G.
 596. Col. Dev., Ilford.
 514,042. Paper, von Bariss (German).
 622. Lenticular.
 955. Sub., Gaspar.
 515,536. Proj., A. G. Tull.
 932. Col. Rend., Gaspar.
 971. " Dev., Kodak.
 516,059. Sub., Gaspar.
 113. Col. Rend., Dufay.
 514. " " Inter. Chem. Corp.
 536. Sound, Kodak.
 584. Sub. Sep. Layer., I.G.
 606. " " " "
 719. Paper, Schinzel (German).
 816. Col. Rend., Macadam (Kodak).
 883. Sub. Dye Dev., Gaspar.
 937. " Sep. Layer, I.G.
 986. Diffract., Col. Res. Corp.
 517,020. Col. Rend., Kodak.
 193. Unclass., I.G.
 197. Col. Dev., Ilford.
 265. " Rend., Kodak.
 328. Filter Layer, Gaspar.
 338. Lenticular.
 416. Col. Rend., Kodak.
 517,424. Sub., Kodak.
 426. Diffract., Col. Res. Corp.
 559. Lab. Dye Des., Gaspar.
 980. Sub., Kodak.
 981. " "
 518,017. Col. Dev., Ilford.
 213. Sub., Gaspar.
 477. " "
 612. Sound, Gaspar.
 715. Sub., Kodak.
 761. Screen, Hewson.
 812. " "
 813. " "
 519,208. Col. Dev., Ilford.
 253. Proj., Kampfner (German).
 419. Sub., Kodak.
 695. Col. Dev., Kodak.
 790. Filter Layer, Gaspar.
 831. Sub. Imb. (Italian).
 520,076. " Kodak.
 173. Sound, Kodak.
 477. Sub., Gaspar.
 527. " "
 528. Col. Dev., Kodak.
 529. Sub., Gaspar.
 575. Filter Layer, Gaspar.
 576. Lenticular.
 521,550. Col. Dev., Gevaert.
 746. Sub., Schinzel (Kodak).
 833. " " "
 834. " " "
 835. " " "
 836. " " "
 837. " " "
 888. " " "
 967. Gaspar.
 522,028. Col. Rend., I.G.
 190. Paper, Gaspar.
 611. Sub. Dye Des., Gaspar.
 650. Unclass., Kodak.
 696. Sub., Gaspar.
 984. " Dye Dev., *Cinecolor*.
 523,018. Col. Rend. Gaspar.
 179. " " "
 230. Sub., Gaspar.
 296. Col. Paper, Schinzel (Kodak).
 507. Sub., Gaspar.
 524,040. Col. Dev., Kodak.
 087. " Rend.
 114. Sound, Kodak.
 154. Multilayer, Kodak.
 320. Filter Layer, Kodak.
 365. Lenticular.
 381.
 500. Filter Layer, Kodak.

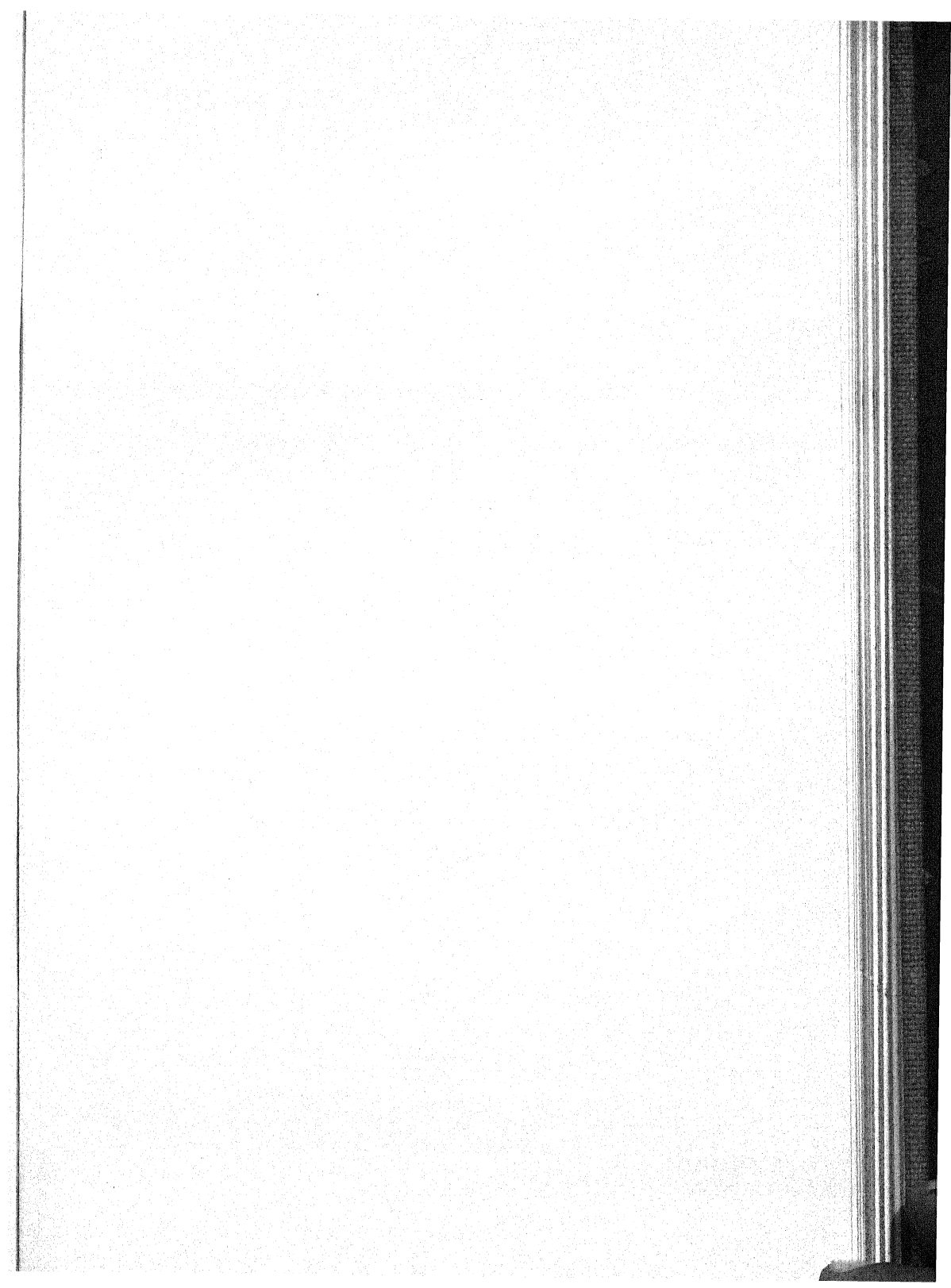
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- 524,552. Sub., Kodak.
553. " "
554. Multilayer, Kodak.
555. " "
556. Col. Dev., Kodak.
557. " "
558. Filter Layer, Kodak.
579. Screen Surround.
588. Filter Layer, Kodak.
996. " "
- 525,549. Sub., *Cinecolor*.
765. Col. Dev., Kodak.
808. Sub., Kodak.
810. " "
874. Col. Dev., Kodak.
875. " "
974. Opt. Printer, Lenticular, (M.L.) (French).
- 526,707. Opt. Beam-splitter, Harrison.
934. Sub. Lenticular Multilayer Coated (French).
- 527,493. Col. Dev., Kodak.
- 529,033. Fast Sensitizers, Kodak.
117. Sub., Filter Layer, Gaspar.
180. " Toning (Spanish).
279. " Gaspar.
440. Filter Layer, Kodak.
674. Sub., Gaspar.
707. Opt.
974. " Gaspar.
- 530,685. Multilayer, Kodak.
- 531,246. Col. Dev., Kodak.
262. " Rend., Kodak.
312. " Dev., Kodak.
- 532,098. Sensitizers, Kodak.
726. Col. Dev., Kodak.
804. " " Ilford.
826. Lenticular.
870. Sub., *Cinecolor*.
- 533,568. Sub., Kodak.
- 534,824. Col. Rend.
- 535,130. Sub., Gaspar.
341. Col. Dev., Du Pont.
410. Sub., Gaspar.
812. Opt., *Cinecolor*.
- 536,228. (M.L.), *Technicolor*.
327. Opt.
329. Fast Dyes, Elliot.
391. Sub., (M.L.), Kodak.
463. Opt., *Technicolor*.
466. Sub., (M.L.), Kodak.
577. Col. Dev., Kodak.
673. " "
702. Sub., (M.L.), Kodak.
781. " "
- 536,939. Col. Dev., Kodak.
- 537,103. Sensitizers, Kodak.
232. " "
256. Direct Coupling with Gel., Kodak.
466. Col. Dev., Kodak.
696. " "
802. Opt., *Technicolor*.
864. Col. Rend.
912. " Dev., Kodak.
928. Hypersensitizing, *Technicolor*.
952. Col. Dev., Kodak.
970. " " "
- 538,012. " " "
013. " " "
100. Couplers, Du Pont.
553. Toning, *Cinecolor*.
556. " "
628. *Technicolor*.
661. Mask. Prints, Kodak.
914. Col. Dev., Kodak.
990. *Technicolor*.
- 539,070. Col. Dev., Kodak.
190. Dye Destruction, Kodak.
228. Multilayer Bipack, *Technicolor*.
266. Col. Rend., Kodak.
270. " " "
325. Couplers, Kodak.
391. Dye Bleach, Kodak.
395. Col. Dev., Kodak.
494. Dye Bleach, Du Pont.
509. Dye Destruction, Kodak.
510. Col. Rend., Kodak.
702. Diffusion, Kodak.
703. Dye Destruction, Kodak.
781. Diffusion, Kodak.
937. Col. Dev., Kodak.
- 540,272. Screen Surround, B.T.H.
363. Prot. Col. Couplers, Kodak.
366. " " "
368. Dye Fixers, Kodak.
382. Resin Acids, Anti-halation, Ilford.
444. Colour Emulsion, Kodak.
445. Filter Layer, Kodak.
451. Non-Diffusion, Kodak.
525. Dye Bleach, Kodak.
541. Prot. Coupler, Kodak.
563. " Col. Couplers, Kodak.
636. Couplers, Kodak.
727. " "
760. " Gevaert.
931. Col. Control, Kodak.
968. Kodak.

- 540,969. Filter Layer, Kodak.
 970. Toning, A. G. Tull.
 971. Multilayer Toning, A. G. Tull.
 974. Toning, A. G. Tull.
 975. Multilayer Toning, A. G. Tull.
 976. Multilayer, Kodak.
 977. " "
 979. Multilayer Toning, A. G. Tull.
 541,073. Dye Dev., Kodak.
 266. Masking, Auto, (M.L.) Kodak.
 298. Col. Rend., Anti-masking, (M.L.), Kodak.
 328. Col. Dev., Kodak.
 335. Filter Layer (in Dye Salts), Kodak.
 345. Toning, (M.L.), A. G. Tull.
 555. " " "
 558. P.C.C., Du Pont.
 589. Fixed Col. Couplers, Kodak.
 589. Oil Couplers, Kodak.
 649. Col. Dev., Kodak.
 771. " " "
 903. Dye Bleach, Kodak.
 542,904. Col. Coupler, Du Pont.
 543,113. Imbibition, *Technicolor*.
 290. Col. Coupler, Du Pont.
 606. P.C.C., Martinez, Kodak.
 544,064. P.C.C., Kodak.
 100. Imbibition Reliefs, *Omnicolor*.
 120. Col. Couplers, Du Pont.
 132. Fluorescent M.L., Kodak.
 134. Non-Diffusion, Kodak.
 135. Couplers in Resin Salt, Kodak.
 189. " Du Pont.
 307. Col. Rend., Kodak.
 545,443. " Dev., Du Pont.
 444. " " "
 448. " " Kodak.
 529. Filter Layer, Dye Resins, Ilford.
 546,347. Col. Dev., Kodak.
 527. Col. Dev., I.C.I. (Du Pont).
 631. Filter Layer, Dye Resins, Ilford.
 667. *Technicolor*.
 704. Dye Bleach, Kodak.
 707. " " "
 708. Filter Layer, Kodak.
 547,064. Col. Dev., Kodak.
 216. Trick Masking, *Technicolor*.
 442. Col. Dev., I.C.I. (Du Pont).
 519. Auto-masking, Kodak.
 722. Dye Toning, A. G. Tull.
 847. Col. Dev., Kodak.
 975. Bleach Bath, Kodak.
 548,342. Substratum, Kodak.
 549,141. Contrast Control, *Technicolor*.
 176. Anti-diffusion, *Technicolor*.
 544. Mask Printing, *Technicolor*.
 587. Toning, A. G. Tull.
 688. Red Absorbing Dyes, *Technicolor*.
 550,028. Filter Layer, A. G. Tull.
 701. " " (Diaz Dyes), Kodak
 994. Toning, Du Pont.
 551,008. Filter, (M.L.), Möen.
 116. Transfer, (M.L.), Du Pont.
 117-120. Col. Couplers in Independent Layers, (M.L.), Du Pont.
 213. Filter Layer, A. G. Tull.
 500. Dye Bleach, Kodak.
 501. Bleach-out, Kodak.
 614. Masking, Kodak.
 799. Metal Toning, A. G. Tull.
 800. Toning, A. G. Tull.
 930. *Technicolor*.
 552,008. " "
 009. Couplers, Du Pont.
 230. Toning, A. G. Tull.
 553,064. Col. Dev., Kodak.
 196. Masking Technique, Kodak.
 229. " " "
 230. " " "
 377. Toning, etc., (M.L.), Coote.
 506. Col. Dev., Kodak.
 507. " " "
 566. Dye destr., Kodak.
 751. Diazo Toning, A. G. Tull.
 752. Selective Bleach, A. G. Tull.
 879. " " "
 952. Toning, A. G. Tull. " "
 961. " " "
 962. " " "
 963. Bipack, A. G. Tull.
 554,302. Reacting Layers, Du Pont.
 555,014. Filter Layer, Kodak.
 167. Beam-splitter, Baird.
 642. " " Gevaert.
 699. U.V. Filter Layer, Kodak.
 728. Anti-diffusion, Kodak.
 556,003. Filter Layer, Gevaert.
 426. Beam-splitter, *Cosmocolor*.
 578. Stereo, Polaroid.
 631. Sound Track, *Technicolor*.
 768. Col. Dev., Du Pont.
 858. Contact Col. Dev., Du Pont.
 557,198. Toning, A. G. Tull.
 750. Anti-fog, Kodak.
 802. " " "

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| 558,099. Fixing Sensitizers, Kodak. | 561,844. Col. Rend., Kodak. |
| 258. Fog Inhibitor, Kodak. | 562,854. Masking, Kodak. |
| 452. Fixing Sensitizers, Kodak. | 565,384. Col. Cor., <i>Technicolor</i> . |
| 855. Col. Dev., Kodak. | 385. " " " |
| 560,573. Selective Separation Mono-
pack Layer, Gaspar. | 836. <i>Technicolor</i> . |
| 561,674. Masking, Kodak. | 566,346. Elec. Opt., Inter. Chem. Corp. |



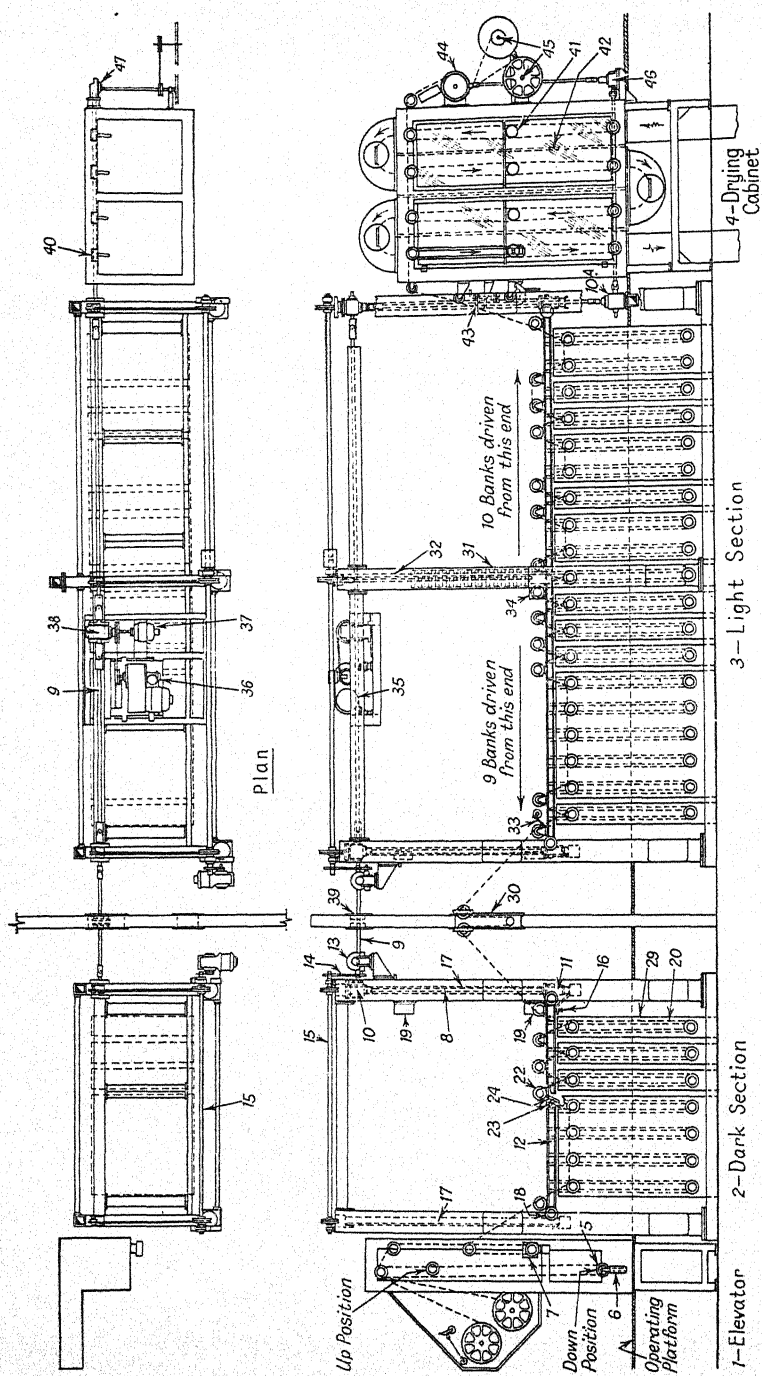


FIG. 326.—The Ansco Color Processing Machine. General drawing.

(Facing p. 673.)

APPENDIX 2

MANUAL.—ANSCO PROCESSING MACHINE. MODEL 4C, FOR 16-MM. ANSCO COLOR REVERSIBLE FILM.

Section I

THE Ansco Color reversible 16-mm. processing machine, Model 4C, was developed by the Ansco 16-mm. Division, with the co-operation of the Ansco Engineering Department. The machine provides the precise control over processing conditions which is so necessary in colour work. It furthermore yields a production volume of a very satisfactory figure—about 3,600 ft. per hour of operation.

This manual discusses the mechanical operation, principles of film drive, installation, and other matters pertaining to the processing units. The plumbing, method of replenishment, and solution-mixing systems are covered in a separate manual. In the near future a manual of recommended practices for Ansco Color reversal laboratories will be issued. This will discuss standardized methods of receiving, delivery, identification, general darkroom practices, solution control, and colour sensitometry.

Enumeration of Units

Referring to the general drawing (Fig. 326), the four main units are, with respect to the direction of film travel: (1) film elevator, (2) darkroom processing section, (3) whitelight processing section, and (4) drying cabinet.

Elevator (1).—Mounted on the front of the elevator cabinet is the film magazine, with film run-out signals. The elevator spool-bank is at 5; the dash pot for arresting the descent of the lower spool-assembly is at 6; and the film breakage indicator is at 7.

Darkroom Processing Section (2).—The Model 4C machine is supported entirely on a specially designed structural steel framework. The use of this steel framework makes the machine entirely self-supporting and eliminates the necessity of supporting the drive and hoisting mechanisms from the ceiling of the developing room—as was customary on the older models. This improved feature makes it easier to align the driving installation and ensures permanent alignment of the parts once the assembly has been accomplished. The main structural steel framework consists of two independent sections—one for the darkroom processing section and the other for the white light processing section. The two are separated by the darkroom wall.

The steel framework of the darkroom section is shown on the drawing by the heavily outlined members. It has many functions. It supports the hexagonal drive shaft (8),¹ which derives its power from the drive shaft (9) coming from the white light section. A spiral mitre gear box (10) forms a junction of the two shafts.

¹ See also the section through A-A on the drawing. Several parts are designated on this and on the plan view—as well as on the elevation—whenever the location or form is better realized in section or plan.

A special gear box (11) travels up and down the hexagonal shaft and is attached to the main spool-bank frame (12). The main steel framework also supports the hoisting mechanism for the spool-bank frame. It consists of a hoisting reduction gear motor (13), drive and hoist chains (14), and shafting (15). The counterweights for the load are housed in the two large corner posts of the main framework. The main framework serves as a support for the spool-bank frame in its processing position at the four corner rest points (16). It also provides vertical guide tracks (17) along which grooved rollers (18) attached to the spool-bank frame travel. On one of the corner posts are located the two limit switches (19) for the spool-bank frame hoist.

The main spool-bank frame (12) is a rigid structure of aluminium angle pieces. It supports the seven film spool-banks of this section (20), the horizontal drive assembly for these (21), the cross-over spools (22), the rubber squeegees (23), and the drip guards under the spools (24). Each spool-bank consists of an upper and lower assembly of spools (25 and 25A),¹ angle side supports (26), the vertical drive shaft (27), and the two gear boxes (28 and 28A). One solution tank is designated at 29, and the others are obvious.

The film passes out of the darkroom section through the light-tight wall pass-box (30).

Whitelight Processing Section (3).—The whitelight processing section is a unit practically identical in principle with the darkroom section. It is, however, a considerably longer unit. This extra length requires centre posts (31) for the support of the steel framework, and vertical hanging support rods (32) for the centre section of the spool-bank frame.

The second exposure unit (33) is located over the first tank of this section. A second breakage indicator (34) is installed as a cross-over spool between the ninth and tenth banks of this section, counting from the pass-box end. The Varidrive unit (35) is located in the superstructure of the steel framework. Other parts which have the same function as identical parts in the darkroom section need not be enumerated again here.

The Transmission of Power.—The remotely controlled Varidrive unit provides power for the entire developing machine. Variable speed of from about 35 to 70 ft. per minute is provided and is under the control of a small motor (36) (reversible in direction of rotation) installed in the Varidrive. This motor is operated by switches at the main control panel. Coupled to the Varidrive is a motor generator (37), the output voltage of which is linear in relation to the speed. This voltage is read at the voltage control panel by a voltmeter calibrated in feet per minute.

The distribution of power from the Varidrive throughout the machine can be traced on the drawing as follows.² The Varidrive unit joins a main overhead horizontal drive shaft (9) through worm gear box 38. This main shaft enters the darkroom section through the light-tight wall junction (39). Power is transmitted vertically downward to each processing unit by three hexagonal shafts (8) through spiral mitre gear boxes (10). Three special gear boxes (11) sliding on the hexagonal shafts transmit the power to horizontal drive assemblies (21) mounted in each main spool-bank frame. These gear boxes slide up and down the hexagonal shafts during hoisting and lowering of the spool-bank frame, and they are bolted to the main spool-bank frames. Power from the horizontal drive assemblies is taken at each spool-bank by mitre gear boxes (28). At the lower spool-assembly a mitre gear box (28A) transmits the power to the spool shafting, to which the film spools are attached by set-screws.

¹ See the section through A-A and the detail drawing.

² See especially the general plan view. The main drive shafts and gear boxes are located on the far side of the machine as viewed in the supplied drawing.

Power for the spool-banks in the drying cabinet is taken off the hexagonal shaft of the whitelight processing unit through a spiral mitre gear box (10A) mounted on a low crosspiece of the main framework. A horizontal shaft spans the separation between the gear box and the drying cabinet and runs through the cabinet. It is interrupted at each lower spool assembly by a mitre gear box (40), into which is geared the spool-bank shafting upon which the spools are assembled and fastened by set-screws.

The Drying Cabinet (4).—Flannel-covered rollers, turning by friction of the contact with the back of the film, are shown at 41. One of the partitions is at 42, the path of air being indicated by arrows. On the machine end of the drying cabinet are mounted the air squeegees (43). On the extreme end of the drying cabinet the compensator roller (44) and film take-up reel spindles (45) are located. Both of these last are driven by shafting geared through two gear boxes (46 and 47) to the horizontal drive shaft of the drying cabinet. Since both the compensator roller and film reels have larger diameters than the regular machine spools, gear box 47 must reduce the r.p.m. of the main machine shafting, and it is, consequently, a bevel reduction gear.

II. General Principles of Film Drive

Friction Drive

No sprockets are used in the machine. The film is carried and propelled entirely by smooth, hard-rubber spools. Therefore, the driving power applied to the film is due to friction between the back of the film and the spool.¹ In order to have this force act on the film, a slight tension must be placed on the film to bring the back of the film against the spool. This tension is of the order of one ounce or less.

It is one of the functions of the compensator roller at the wind-up to apply this tension. If, while the machine is running, the compensator is disengaged (and the wind-up reel also), slack will begin to form in the last bank of the drying cabinet and will progress in wave form towards the elevator. At the exact moment slack forms at any lower drive spool, the spool stops driving. In a few seconds the film will stop driving in all parts of the machine. If, on the other hand, the compensator is engaged, slack will be taken up at the last roller of the drying cabinet and progressively from there all the way back to the elevator, and driving force will be applied at each spool at the moment slack is taken up.

An identical action takes place whenever a break in the film occurs in either of the processing sections or in the drying cabinet. This principle then becomes very important, because the film behind the break stops, and therefore cannot pile up in the machine at the breakage point. Breakage indicators will signal an immediate shut-down before the two sections of the film have separated too far to permit an emergency splice to be made.

More important still is the behaviour of the film driven by this principle in its normal path through the various solutions. It is well known that film expands in length and width as it becomes wet during processing. It also expands and contracts in passing from baths of different temperatures, or of different chemical compositions, but the general tendency is one of progressive expansion, especially during the first half-hour of wetting. This property of film must be compensated for in machine development, or undue amounts of slack will form on the spool-banks. Our application of the friction-drive principle does this efficiently. When a slight amount of slack forms under a spool, the spool does not assist in propelling

¹ The film rollers, or spools, are undercut with a shallow radius, but a slightly rounded shoulder is provided as a bearing surface for the extreme edges of the film—outside the perforations.

the film, a slight delay of film drive takes place, and the spools ahead of the non-driving one take up the slack. The process is, of course, of momentary nature and not observable in the ordinary examination of the machine, since no detectable amount of slack is ever permitted to form. It is also correct to think of the spools as being driven slightly faster than the film, since a small amount of slippage must take place momentarily on all driven spools which are carrying expanding film.

Lower Spool-Assembly Drive

It may be asked why the lower spool-assemblies are the driven ones while the upper spools are allowed to idle. The upper and lower (driven) spool-assemblies serve entirely different purposes. The upper assembly can be considered the film carrier, for it is these spools which support the weight of the film. The lower assembly is the driver, and this assembly serves to supply the power for conveying the film through the machine. We have seen that a valuable principle of the machine lies in its refusal to drive slack film, since the film will lose contact with the lower (driving) spools. If any of the upper spools were driven, the weight of the film hanging on the spools would give sufficient friction to cause driving of the film—even though a break or considerable amounts of slack might lie ahead of the driving points.

A further precaution is taken to prevent the driving of slack film. This lies in the large washers which separate each spool of the upper spool-assemblies from its adjoining two spools. This washer is keyed into a slot in the shaft and cannot turn. It effectively prevents any top spool from driving its neighbouring spools by friction between the flanges.

Compensator Roller

When the wet film enters the drying cabinet it begins to lose its accumulated water, and in so doing starts to return to approximately its original dry dimensions. By about the middle of the third drying cabinet spool-bank, the film has become dry to the touch and appreciably shorter than it was on entering the drying cabinet. It is obvious that the film cannot be taken out of the cabinet at the same rate that it was put in. It is the function of the compensator roller to compensate for this difference. The film entering the cabinet has a rate practically equal to the main spool-drive speed as calculated from the spool circumference times the r.p.m. The compensator, however, must have a slower delivery rate than this—a value of about 0.8 per cent. less than the main spool-drive. Therefore, the compensator has a circumference smaller by this value than would be required for it to deliver film at the rate of the main spool-drive. With such compensation, the film throughout the drying cabinet remains at normal tension.

III. Discussion of Units

Elevator (1)

Elevator Magazine.—The elevator magazine has two reel spindles, each of which is fitted with two friction clutch plates to prevent the reel of film from turning too freely, and thus eliminate slack formation at the loading point. The friction is adjustable by a coil spring, washer, and nut assembly, which presses the two clutch plates together—a large felt washer being between the clutch plates. This adjustment should be at the minimum necessary to prevent slack formation as the film leaves the reel. The best test of the adjustment is made with both a full reel and an almost empty reel, since the resistance to rotation of the spindle varies with the amount of film on the reel. While the machine is in operation, closely observe the performance of the lower spool-assembly (of the elevator) in the light of the given friction adjustment of the reel spindles. The elevator should, of course, stay open during

normal running of the machine. Furthermore, if the film is clamped for splicing purposes, the elevator will start to close. As it opens on the release of the clamped film, and starts to travel slowly downward, the behaviour of the supply reel when the lower spool-assembly contacts the arrestor is to be closely watched. The counter-weighting of the lower spool-assembly is, of course, a factor to be considered here (discussed under *Elevator Cabinet*, page 678). In general, it may not always be possible to secure an ideal adjustment of the several factors involved. It is frequently necessary to check by hand the too rapid feeding of the film off the supply reel during the fall of the lower spool-assembly, especially immediately after it contacts the arrestor.

It should be added that whatever minimum adjustment of the spindle friction plates is made, it should be sufficient to prevent slack formation on starting and stopping the machine drive.

It is plain that a friction adjustment of this kind results in placing a tension on the film going into the elevator and also on the film in the elevator. The value of this tension is greater than the one ounce or less required to drive the film in the processing sections. This fact is not alarming, since the dry film will tolerate considerably more tension than the wet film. A similar condition of unusual tension exists at the film wind-up reel on the very end of the machine, where higher tension is necessary to wind up the film properly. Here again the film is dry. Nevertheless, tension should in the best practice be kept down to the minimum values required. Tension at all points in the machine may be measured by splicing a large rubber band into the leader and running it through the machine. At various points in the machine the amount of stretch of the rubber band is measured and recorded. The rubber band assembly is thereafter calibrated by removing it and loading it with various balance weights. For each weight a stretch value is measured from the rubber band. The relationships can be graphed to assist in interpolating between measured values.

Each supply reel spindle is supplied with a simple device to annunciate the revolutions of the spindle by means of an audible signal. As long as the operator hears this signal, he knows that the supply reel is paying out film. An additional safety device may be installed inside the elevator cabinet; this consists of a microswitch mounted on the inside partition and a contact-making piece mounted on the lower spool-assembly. When the spool-assembly rises, the microswitch is closed and a bell or buzzer sounds. The operator knows that this signal means the elevator is closing, and if this occurs when the film should be feeding into the machine, the difficulty is remedied at once before the film breaks owing to a closed elevator.

Each spindle is further supplied with a film run-out warning signal device. On the end of this device a small plastic roller is fitted. During operation of the machine, this roller rests on the back of the film on the reel. The operator should check daily to see that this roller turns freely. A time-adjustment of the signal device is to be made on installation. The set-screw which locks the arm to the shafting is loosened, the plastic roller is placed in contact with about 60 ft. of film on the standard reel; now, while the lever arm behind the loading cabinet is held against the microswitch, the set-screw is set in tightly. This will give about one minute warning of the film run-out. A second adjustment is made at the microswitch, where a set-screw is adjusted to prevent more than the necessary pressure being applied to the switch button.

The machine is designed to operate with 1,600-ft. reels, which must be of the steel-flanged type. Square spindle holes are necessary on both sides. Ill-fitting reels are apt to wobble on the spindles. At the elevator magazine this may cause the small plastic roller to make lateral scratches on the back of the film. In the case of the wind-up reels, the edges of the flanges may *saw* the edges of the entering film. Many reels are observed to have sharp edges on the circumference of the flanges. These are injurious, especially if they become nicked. Such reels should be put on a lathe

and the edges rounded off with file and buffing paper. Reels should be kept clean and should be stored in the cans provided for this purpose.

The reels are loaded on the spindles in such a manner that the film, which should be wound emulsion side inward, is fed off the bottom of the reel, and the film passes directly to the first left-hand spool of the upper bank in the elevator, without twisting in its path. Since provision has been made in the magazine for two reels, it is well to take advantage of this by keeping two reels of film loaded at all times, the one reel being, of course, in reserve. This will reduce the time involved in splicing on a new reel when required, since it will not be necessary to handle reels at the change-over. When the run-out buzzer sounds, the operator should take the film by the edges (*only*) and be alert for the run-out. When the end of the film leaves the reel, the film is clamped in the little device installed for this purpose. About one foot of film is left free for splicing on the next reel. Care is taken that the film does not loop off the circumference¹ of the new reel and that it is fed directly from the bottom of the reel to the elevator, clear of the clamping device.

Elevator Cabinet.—The elevator cabinet consists of an upper and lower spool-assembly, neither being machine-driven. The lower one is mounted on a chain suspension which permits it to rise almost to meet the upper assembly. This is a unique principle of elevator spool suspension and equalizes uneven torque in the elevator chain and sprocket suspension. If the end of the film is clamped for splicing, the length of the film in the elevator becomes shorter as the forward processing sections pull the film out of the elevator. The elevator holds sufficient film for about two minutes' operation at normal speed. After the splice has been made and the film released, the elevator opens as the lower spool-assembly falls slowly to the bottom of the cabinet, where its fall is arrested by the mechanical dash pot. To provide film for this expansion, the supply reel must feed faster than normally.

The tension on the chain suspension is adjustable by turnbuckles, and this should be set at the minimum required to maintain the spool-assembly in its proper path and equalized on both chains. In order to fall, the spool-assembly must overcome the resistance of the friction of the chain and bearings, the friction of the several ball-bearing film spools and of the supply reel spindle friction plate. The weight of the lower spool-assembly is more than sufficient to do this, and in order to prevent its too rapid fall it is counterweighted by mounting containers of lead shot on the reverse side of the chain suspension. The amount of this counterweighting should be the maximum which will permit the lower bank to fall from a raised position, while pulling the film off a supply reel which has only a few turns of film on it, and which is under friction due to the clutch plates of the reel spindle. It should also be equalized between the two chains. Too little counterweighting would place unnecessary strain on the film when the lower bank is in a raised position; while too much would not, of course, permit the bank to fall to its lower position. The practice of starting the lower bank down with a strong pull should be discouraged, since this strain must be taken up by the film on the spool-bank.

Breakage Indicator.—Just before leaving the elevator cabinet, the film is looped around the spool of a breakage indicator. This spool is kept rotating by the film travel. If the rotation should cease—as will happen in the case of a break—a circuit is closed to ring a bell or buzzer. The electrical principles of this are discussed in Section V, page 683.

Darkroom Processing Unit (2)

Main Spool-Bank Frame.—The several parts of the darkroom processing unit have been enumerated, the power transmission from the Varidrive to the lower spool-banks traced, and the hoisting system for the main spool-bank frame outlined.

¹ It has been found preferable to load only 1,400 ft. of film on the 1,600-ft. reel.

The main spool-bank frame is a large structure of aluminium structural pieces to which the spool-bank supports are bolted. In the "U"-shaped side at the back of the machine is located the drive shaft assembly for the spool-banks with its short shafts, couplings, and gear boxes. The hoist chains are attached to the spool-bank frame at the four corners, and in the operating position, the frame rests on four levelling bolts at the four corners. These bolts are installed on the main steel framework (except at the elevator end, where they are threaded into the aluminium frame). The spool-bank frame has two grooved rollers on each end which run along the vertical guide tracks built on to the main frame. On the spool-bank frame are mounted the cross-over spools between tanks, with drip guards, and the solution squeegees.

The Spool-Bank.—The features of the seven identical spool-banks of this section will now be discussed with reference to the detail drawing on the supplied general assembly drawing. Each bank consists of four stainless steel angle supports (26) bolted to the aluminium frame on one side and to the gear box on the other (driven) side. These serve as supports for the upper spool-assembly shaft and for the bearings and gear box of the lower spool-assembly shaft. On the upper shaft are mounted twenty-five hard-rubber, free-turning spools. Each of the spools is separated from its neighbours by washers keyed into a slot in the shaft. The shaft is indexed to the support by a pin in the shaft, and the slot is faced downward. A total of $\frac{1}{8}$ in. spool clearance is left on the shaft, and this is distributed among the spools and the washers across the shaft.

The lower spool assembly consists of twenty-four spools, attached to the shaft by set-screws and separated by plates (48), which have the function of preventing slack loops from slipping over the spool flanges. The plates are supported by the aligning shaft (49) for the shaft bearings. A small loop guard shaft (50) is inserted through the plates under the spools to keep the film in the proper channel.

The lower spool shaft enters the mitre gear box on the driven end and is rotated by a vertical shaft entering this mitre gear box.¹ This shaft extends upward into the upper mitre gear box bolted under the "U"-shaped aluminium frame.

The lower shaft bearings and gears are lubricated by the solutions in the tanks. The top gears operate in a grease case. The outlets for the shafting of this top gear box are fitted with self-adjusting oil seals (52). As an additional precaution, grease-catching cups (53) are installed around the vertical shafts immediately under the gear box.

The spools of the upper assembly have Parock graphited rubber bushings intended for aqueous lubrication. Bushings are not necessary in the lower (driven) spools.

Spare parts for a complete spool-bank must be on hand at all times. This should include a factory-assembled lower spool-assembly, complete with gear box.

It will be observed in the detail drawing that the designers have planned a certain location for each bottom spool relative to the top spools of any single film loop. Specifically, the space between any two top spools is vertically over the centre of the bottom spool. The reason for this is that the film must advance across the spool-bank, and this advance is distributed equally between the top and bottom spools. The maximum angle of lateral displacement is thus cut in half, in order to obviate any possibility of edge stretching the film.

The Tanks.—The first four banks are for the large first-developer tank. Each bank carries 187 ft. of film. Multiplying this by four and adding 2 ft. for cross-over, the footage in this tank is 750 ft. fully threaded.

¹ This vertical drive shaft is coupled with the lower gear box by a special coupling (51) which is locked with a taper pin. Should the driven spool-assemblies jam for any reason, this pin is expected to shear before damage is done to the gears or drive shafts.

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The required time of immersion is obtained both by an adjustment of the machine speed and (if necessary) by skipping loops. The general formula for figuring these relationships is:

$$\begin{array}{rcl} \text{Machine speed} & \times & \text{Immersion time} = \text{Footage travelled by film.} \\ \text{(feet per minute)} & & \text{(in minutes)} \end{array}$$

In general, one of the processing baths will be the limiting factor, and the machine speed will be adjusted to give the film in this tank the proper immersion time, with the banks (or bank) completely threaded. If, at this established speed, the treatment in any other tank is figured to be too long, loops must be skipped in these tanks to obtain the proper timing.

The tanks of this section are made of stainless steel, with bottoms sloping to an outlet to facilitate cleaning when necessary. An overflow outlet is near the top. The solution recirculation intake is introduced into the tank a few inches below this. The developer tank is fitted with jet tube inlets. These are installed between spool-banks and have orifices pointing both upwards and downwards. The other tanks of this section are single-bank tanks, and, while the solutions are continuously replenished, no recirculation is required.

The film passes out of the first developer, through the rubber squeegees, and goes over the cross-over spool into the next tank—a rinse tank. In the Model 4C, two or more loops are to be rinsed.¹ Each loop is 7 ft. 8½ in. long. The cross-over spool out of this rinse tank is a special one set on an angle to lead the film across to the piping side of the clearing bath. The clearing bath is a single-bank tank, as is the following hardener tank.

Pass-Box.—The film crosses to the whitelight processing section through the light-tight pass-box in the wall between the processing sections. Locking mechanism within the box prevents both doors from being opened at once, thus eliminating the possibility of whitelighting the first developing room. An additional pass-box wall frame with cover panels is to be mounted in the wall on the other side of the machine. The pass-box may be switched over to this frame if it should ever be necessary to use the spare tank in the whitelight section or skip a bank anywhere. This switch would bring the film out of the last tank on the air squeegee side of the drying cabinet—after a not too inconvenient shift of the elevator cabinet from its presently planned location to the other side of the machine.

Whitelight Processing Section (3)

Second-Exposure Device.—The film coming out of the darkroom passes into a wash tank of one bank. Over this tank and mounted on the end of the main spool-bank frame is the second-exposure device. This consists of a mount for several lamps. Heavy-duty waterproof sockets and wiring should be provided here. The lamps are switched on and off by the main drive switch to prevent melting film in the event of stoppage of drive. In the centre of the wash bank the film is carried up over a raised spool to give additional exposure, especially through the back of the film.

Special Features.—As already noted, the whitelight processing section of the machine consists in general of units similar or identical in form to those in the darkroom processing section. It will therefore be necessary to point out only the special forms here. The main framework and spool-bank frame are much longer, because they must accommodate nineteen spool-banks. Two additional posts for the main framework are provided in the centre of the span, and the long spool-bank frame

¹ It is preferable, from the viewpoint of preserving the short stop and hardener in the following tanks, to rinse as many loops as the temperature and softness of the wash water will permit. This is especially important in the case of the rinse following the colour developer tank.

is supported in the centre by hanging stainless rods (32), with adjustable stop nuts where they enter the aluminium structural pieces.

The Tanks.—The colour developer tank is a large jet-circulated tank containing five spool-banks, and thus provides a maximum footage of 938 ft. This is followed by the same sequence of short rinse, clearing, hardening, and washing as was given in the darkroom section. Four single tanks are used. Then follows a two-bank jet-circulated bleach tank, which is exceptional in that the tank is made of rubber-coated steel. In this tank the spool-bank side members are coated with "Lastiglas," a baked-on bakelite, anti-corrosion coating. The footage of the two-bank tank is 375 ft. A regular stainless steel single-bank wash tank follows, then a two-bank hypo tank, which is jet-circulated. Cross-over is made to a single bank wash tank, a spare tank follows, which the film skips in the present process,¹ then a two-bank final wash tank. This division of the wash into two tanks gives a more efficient washing operation. In the wash tanks, water is introduced at the bottom and overflows at the regular overflow outlet near the top of the tank.

Drying Cabinet (4).

Air Squeegees.—As the film leaves the whitelight solution section, it is threaded through the air squeegees. Compressed air at 8 to 10 lb. per square inch pressure is blown on the film passing between paired nozzles, having narrow slits to concentrate the blast. These slits should be adjusted to point slightly downwards from the horizontal. With correct adjustment, superfluous water should be cleared from the perforations and all surface water removed from the film, and the film surfaces will not contact squeegees. For the adjustment and care of the air pump, the supplier's manual should be consulted, and any special instructions required to supplement the present manual will be supplied by Ansco.

Cabinet.—The drying cabinet has four long spool-banks, each in a compartment separated from its neighbour by a partition, but interconnected by both top and bottom air ducts. Each bank consists of an upper assembly of idling spools and a lower assembly of driven spools with loop guard plates. The top spools have Oilite bronze bushings. Between the upper and lower banks is suspended a large Canton flannel-covered roller to polish the back of the film. The lower banks are driven by power from the Varidrive, as previously explained. Air from the Bryant silica gel dehydrator is introduced into the drying cabinet at the last spool-bank and is exhausted back to the dehydrator at the first bank. The silica gel unit supplies clean, dehydrated air. Normally, the dehydrator is adjusted to supply air of 30 to 35 per cent. R.H., and a temperature of 85° to 90° F. Its introduction at the last spool-bank is obviously to treat the film about to leave the cabinet with the driest air. For operation and maintenance of the silica gel unit, the supplier's manual should be consulted.

Compensator Roller.—The functions of the compensator roller—a rubber-tyred wheel whose outside diameter is 8.8 in.—have been discussed and the mode of its drive outlined. During the change-over to a new reel at the wind-up, the compensator keeps a constant pull on the film, and therefore no slack is let back into the spool-banks.

The film is led over the outer rim of the roller and then between this and the small rubber pressure roller, and from here to either wind-up reel directly. It is important that no film slippage take place on the compensator. Therefore, the small rubber roller must always be in firm contact with the compensator; an adjustable spring accomplishes this. The adjustment of the spring should be checked every few months. Make the test by pulling out slack from the drying cabinet, shut off the machine drive, and try to pull the slack film around the compensator by turning

¹ Type II Improved—with double hardener and short stop.

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the wind-up reel by hand. The film should resist any reasonable amount of torque on the take-up reel; that is, it should refuse to slip around the compensator roller. When this condition has been met, the pressure of the small roller on the compensator is sufficient.

Wind-up Spindles.—The power for the wind-up spindles is taken off the compensator shafting by leather belts. Two spindles are provided in order to eliminate handling of reels on the change-over. Each spindle is mounted in a bracket which is so hinged that it may pivot up and down over a small arc to assist in engaging the leather belts. The downward swing is limited by a set-screw which is intended to relieve the belt of most of the weight of the assembly and to control the amount of torque applied to the wind-up reel. This adjustment is so made that a minimum tension is applied to the film coming off the compensator, the minimum being arrived at when the film winds up with just acceptable tightness.

IV. Installation

Reference to the floor plan (obtainable from the Ansco Engineering Department) will give the dimensions of the concrete footing piers which are to be prepared for the main steel framework of the two processing units. They are to be 4 in. above the level of the floor. When the concrete for these is poured, stud bolts to take the steel foot plates are set in and spaced exactly according to dimensions taken off the machine. The main framework is later set down over these bolts. Wedges are then applied to raise the foot plates an average of $\frac{3}{8}$ in. higher. This operation must be checked against the vertical guide tracks (inside edge), *which should be plumb.*

The darkroom and whitelight sections must be in alignment with each other, since the main overhead drive shaft must be coupled between the two units without undue amount of offset. Universal joints provided here will correct minor misalignment. Alignment must be carefully checked. Between the darkroom wall and the processing sections, sufficient space should be provided to permit walking across the machine at these points.

The pass-box frame is installed in the wall with the entrance or exit spools 4 ft. $11\frac{1}{2}$ in. above the operating platform¹ and so aligned laterally that the film, in passing from one processing section to the other, follows a practically straight line. The extra wall frame is similarly installed at the other side of the machine.

The elevator is set up on its angle-iron frame² and so positioned that its exit spool is in line with the entrance spool of the darkroom processing section. The spacing from the steel posts of this section should be sufficient to allow cleaning between the two units—about 6 in.

The drying cabinet is likewise set up on its angle-iron frames and separated from the steel frame of the whitelight processing section by an amount sufficient to allow an operator to pass between the units.

The lateral location of the drying cabinet must be arranged to engage the bottom horizontal drive-shaft with its gear box on the main steel framework. Very probably the height and level of the angle-iron frame will have to be adjusted to some extent with shims properly to line up the shafting. The couplings in this shaft are of the three-pronged type with fibre inserts, and will take care of slight misalignment. Couplings of this type are set with an appreciable clearance between the face of the prongs and the seat in the coupling member, since this makes for quieter operation. When properly lined up, the foot plates of the frame should be bolted to the floor

¹ Ansco drawing No. 14,092—E4 General Assembly.

² In installations where a concrete operating platform is planned, the elevator should be set directly on the concrete.

using expansion lugs. This is also done with the angle-iron frame of the elevator. Both wooden cabinets are then bolted to their iron supports.

Each spool-bank frame is to be levelled up on its four corner rest points. The average adjustment should place the upper surface of the upper spool shafts level with the bottom of the overflow fitting of the solution tanks.

The hoist chains are adjusted by turnbuckles. Sufficient slack should be in the chains to relieve them of the weight of the main frame when it lies on its rest points. The chains on each frame are adjusted equally so that the hoist will be applied at all contact points of the machine uniformly.

With the main frames installed and partly lowered, the tanks are to be located under the spool-banks. The tanks are centred with respect to the spool-bank (or -banks) on the long dimension of the machine. The location laterally is obtained by allowing 3 in. clearance between the inside of the tank (piping inlet side) and the centre of the vertical drive shaft of each spool-bank. Measurement will show

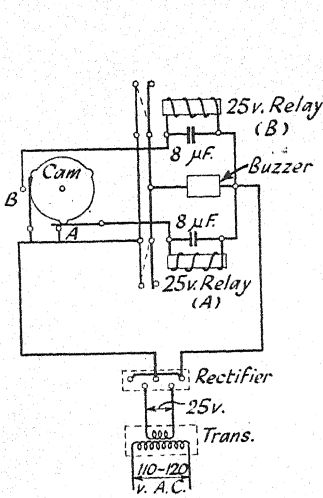


FIG. 1.—Breakage Indicator.

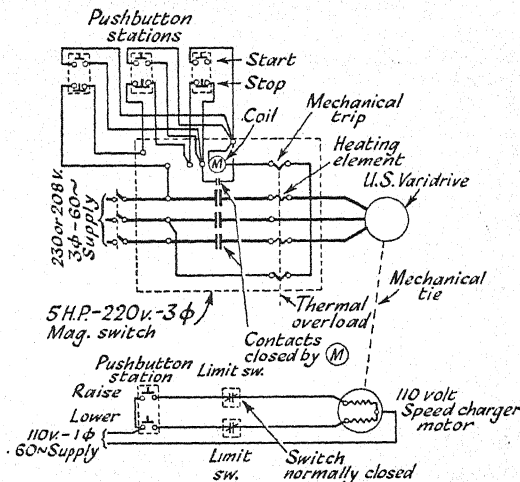


FIG. 2.—Varidrive and Speed Changer Motors.

about $2\frac{1}{4}$ in. clearance on the other side of the tank, between the spool-bank angle side pieces and the inside of the tank.

It is not necessary to bolt the tanks to the floor. They are simply set directly on the concrete floor and shimmed up to level if required.

V. Electrical Units

1. Breakage Indicator

In Fig. 1, the cam and microswitch unit of the breakage indicator is shown with its electrical circuit. The cam is kept turning by the film, which is passed over a spool mounted on the same shaft as the cam. At intervals, the cam, as it turns, closes the circuit to the relay coils by depressing microswitches A and B. The relays are thereby energized and the contacts opened. During the short period when the cam does not depress the microswitches, the condensers hold the relays sufficiently energized to maintain the contacts open. If, however, the

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cam stops turning (as when a film break occurs), either one or both of the micro-switches are left open, the condenser loses its charge, the relay is de-energized, and the circuit is closed to the buzzer. The film spool, cam, and microswitch unit are mounted in the machine. The remaining electrical apparatus is mounted outside the immediate machine area.

2. Tachometer Generator and Speed Indicator

A G.E. Model No. 5BC46AB763A tachometer is tied to a G.E. Model No DD7 speed-indicating instrument, calibrated for a range of 0-80 ft. per minute. The meter is to be mounted near the drying cabinet in the whitelight section, and its simple circuit need not be diagrammed.

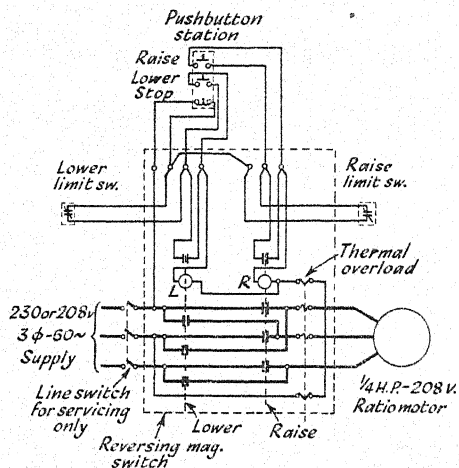


FIG. 3.—Hoist Motors.

3. Varidrive and Speed Changer Motors

In Fig. 2 the circuits for the Varidrive (V.S. Type V.E. Frame No. 12-59, 1,800-1,900 r.p.m.) and its speed control motor are shown. The control motor (110-volt, single-phase) is operated from a watertight raise and lower push-button station located at the speed indicator meter in the whitelight section. A limit switch is in the raise and lower portion of speed control motor circuit. Three watertight push-button stations for starting and stopping the Varidrive motor are to be installed. One is to be located in the darkroom section on the front corner post of the machine next to the elevator cabinet. A second station is to be located in the whitelight section on the front corner post of the machine next to the pass-box. The third is to be located on the front corner post of the machine next to the drying cabinet. The magnetic motor starting switch is to be located outside the immediate machine area.

4. Hoist Motor (Whitelight Section)

Each hoist motor is controlled by means of a reversing magnetic switch mounted on the wall opposite the front of the machine and in the approximate centre of the processing section. It is actuated by means of a watertight raise, lower and stop-button station with limit switches for overtravel control (see Fig. 3).

5. Hoist Motor (Darkroom Section)

This is the same specification as the hoist motor in the whitelight section. The switches are to be mounted on the wall opposite the front of the machine.

6. Second-Exposure Device

A bank of incandescent lamps is to be mounted over the wash tank following the pass-box in the whitelight section. The lamps are to be fed from the secondary side of a 5-KVA insulation transformer. The lamp circuit is to be controlled by a relay. The coil of this relay is fed from the load side of the magnetic switch of the Varidrive (see Fig. 4). When the film drive is stopped for any reason, the relay cuts out the second-exposure lamps, and thus prevents overheating the film in the area of the second-exposure device.

7. Circulating Pumps

All circulating pumps are to be controlled from watertight manual starters located on the wall opposite the front of the machine in the whitelight section.

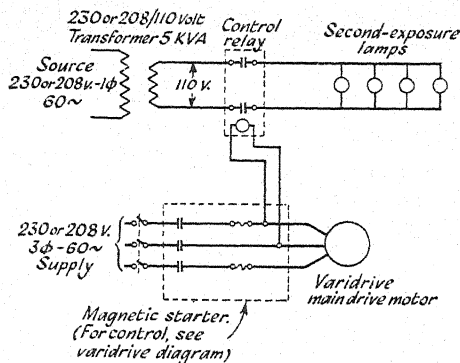


FIG. 4.—Second-exposure device.

8. Signal Devices for Film Elevator

A microswitch operated from an arm riding on the film on the supply reel closes a 6-volt A.C. source into a bell circuit giving an audible signal when there is only 60 ft. of film left on the reel. A line switch should be provided in the 110-volt supply to the transformer feeding this set-up to enable disconnection of the signal device.

9. Switch for Drying Cabinet

The silica gel dehydrator is to be switched on and off at the drying cabinet by a push-button station operating a magnetic starting switch located outside the immediate machine area.

10. The Nash Air Compressor

The Nash Air Compressor, which provides air for the squeegees, is to be turned on and off by a push-button station located on the drying cabinet near the squeegee. This push-button station operates a magnetic starting switch outside the machine area.

VI. Leader Considerations

The leader taken into the total machine is about 6,320 ft., or about one and a fifth miles of film. The leader time is about one hour, forty-five minutes at 60 ft.

per minute. The leader stock is unperforated white opaque cellulose acetate base for colour machines. *Ethyl cellulose, used for black-and-white machines, must not be used for colour.* The preferred leader thickness is 170 to 180 μ . It is black on one side and white on the other. The black layer makes the two sides easily distinguishable under darkroom safelighting. The leader normally is run black side up.

Whenever necessary the leader is spliced. This is done in such a manner that the splice will run through the machine spools according to the following illustration:

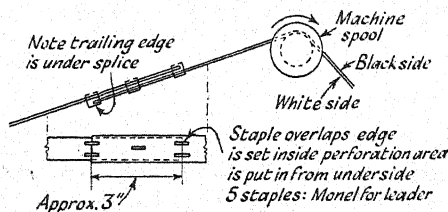


FIG. 5.

After each run, the leader is slowly rewound, as the edges run between the fingers, and is carefully examined visually and by touch for tears, deformations, and weak splices. The life of the leader is increased by avoiding unnecessary tension at all points in the machine and by careful handling in general.

Threading the Leader.—With the machine running, the leader is threaded over the spools. Two operators on both sides of the spool-bank, one on the upper spool-assembly, the other on the lower, should without difficulty be able to thread the leader at normal machine speed.¹ While this is being done, it is advisable to lubricate all the lower spool shaft bearings with a solution of glycerine and water (1 : 1).

Neither a wet nor even a dry leader should be left on the spool-banks out of the solutions without accumulating considerable slack at each bank, since a change in R.H. or normal drying would shrink the leader and cause warping of the shafts and damage to the machine and leader. Slack must always be pulled into each bank of the drying cabinet on closing down the machine. To obtain slack, the compensator and wind-up reels are disengaged and the spool-drive started. The leader in the solution tanks is, in practice, never left out of the solutions longer than necessary to service the spool-banks, and if the job is a long one the leader should be run out of the machine normally.

VII. Maintenance

Under this subject come the various cleaning and lubricating jobs, which must be scheduled and then strictly adhered to, or situations are liable to develop which would work to the detriment of the output, both as regards quality and quantity.

Cleaning

Daily jobs.—At the beginning of each shift, the operators should perform the following duties:

- (1) Clean and polish the air squeegees with crocus cloth. If any roughness of surface is noted on the nozzles, this is to be removed with very fine emery paper and polished smooth with crocus cloth.

¹ To reduce the threading time, a second group of operators may start threading at a point in the machine about midway down the whitelight section. The leader is supplied from a reel on a rewind clamped on to the spool-bank frame.

- (2) Wipe out the grease catcher cups on the drive shaft of each spool-bank.
- (3) Wipe off the two compensator rollers, using a clean, damp cloth, then dry the rollers.
- (4) Clean the solution squeegees of any accumulations. A solution of nitric acid and water is helpful if calcium carbonate deposits form.
- (5) Clean the cross-over spools, the pass-box spools, and the air-squeegee spools of any accumulations.
- (6) Daily check all bottom and top spools for any calcium carbonate deposits which may form. If hard water is present, these deposits are especially common and must be constantly removed. Abrasions and scratches on the back of the film are the result of neglecting this accumulation. It should be removed whenever necessary as described below under Monthly Duties (2).
- (7) During operation, the machine frame, supports, outsides of tanks and other equipment must be kept clean at all times by wiping off spilled solutions with a damp cloth.

End-of-Week Duties

- (1) Wipe the inside of the drying cabinet, including spools and air ducts, with a clean, damp cloth.
- (2) At the same time, whatever parts of the main steel framework, spool-bank frame, and elevator can be reached from the operating platform should be wiped clean.
- (3) The working platform is to be hosed off or mopped.
- (4) The outsides of the tanks are to be hosed off or otherwise cleaned.

Monthly Duties

- (1) General cleaning of all dust-catching surfaces about and over the machine with soap and water. The inside of the drying cabinet may be included here for a more thorough cleaning than the weekly one.
- (2) The spool-banks should be cleaned thoroughly. The leader is run out through the drying cabinet, and then the tanks are covered with the plywood sections provided; these are covered with the rubber blankets to prevent cleaning acids and water from contaminating the processing solutions in the tanks. The covers of the whitelight section are cut to join between tanks, so that the blankets can hang down between this division. Those banks which accumulate an encrustation of water salts are cleaned with nitric acid diluted about 1 : 3 in water. To do this job properly, stainless steel cleaning pans are provided. The top spool-assembly is removed from its supports and immersed in the special pan of dilute acid. The lower assembly is treated by blocking up the special pan under the parts. The angle side pieces and the shafting are treated by swabbing the acid from a pan up the length of the member. Some of the spool-banks may be cleaned easily enough by scrubbing with a bristle brush and water. Such banks need not be acid treated. All parts must be well hosed off to complete the job.

Occasional Cleaning

The spools in the first developer, hypo, and certain other tanks will slowly accumulate a plating of silver, evidenced by a greyish metallic sheen. This can be removed by treating the spools in strong nitric acid about 1 : 1, followed by a water rinse.

Irregularly-Scheduled Jobs

- (1) On the occasion that a tank is emptied, it is immediately hosed out or, if necessary, scrubbed clean. Water tanks should be frequently cleaned to remove any bacterial deposits if they occur.

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- (2) Tanks which have had solutions in them for a considerable time should be dumped at the first opportunity and scrubbed clean.

Lubrication

Discussion of lubrication is divided into three parts: (a) shaft bearings, (b) motors, and (c) gear boxes.

(a) *Shaft Bearings.*—Where a ball-bearing must work with the greatest freedom, it is advised to oil sparingly with a good grade of machine oil (viscosity S.A.E. 10), let drain, and wipe off excess oil thoroughly. If a ball-bearing is under a greater load, a light cup grease¹ is recommended. It is considered neither necessary nor otherwise desirable to lubricate the spool bearings anywhere in the machine. The spools in the elevator have ball-bearing inserts and, owing to the light load, never require oil. The upper spools in the processing sections have brushings of a special graphited rubber and are intended to be lubricated by the processing solutions. The spools in the drying cabinet have Oilite bronze bushings and are self-lubricating. However, should any of these spools stick or not turn freely, they should be dismounted and the bearing surfaces cleaned with kerosene.

The following is a list of bearings which should be lubricated as directed every six months unless otherwise stated:

- (1) The breakage indicator spools are on ball-bearings; oil at the plugs provided. Wipe off excess oil.
- (2) The reel spindles are on ball-bearings; dismount the shafts and oil bearings lightly from the sides.
- (3) The lower spool-bank shaft of the drying cabinet is supported on one side by Fafnir bearings; grease at the plug, if they ever need lubrication.
- (4) The polishing rollers in the drying cabinet are on ball-bearings; back off the end-collars and oil sparingly from the side. *Wipe off excess oil.*
- (5) The compensator wheel is on a Fafnir ball bearing; grease at the plug.
- (6) The sprocket wheel and chain drive of the spool-bank hoist use both sleeve and Fafnir bearings. Grease the Fafnir bearings at the plug if they ever need it, and oil the sleeve bearings. This need not be done more than once every year or two.
- (7) The hoist chains should be wiped with an oily rag occasionally to prevent rust. This should also be done to the chain suspension of the elevator.
- (8) The Fafnir bearings of the main drive shaft are to be greased at the plug.
- (9) The several universal couplings are to be oiled sparingly and checked for excess. The other couplings are chiefly of the three-pronged insert type and should not be lubricated.

(b) *Motors.*—Either grease or oil is required, as indicated by the manufacturers. The frequency of lubrication is very variable, as will be noted. The manufacturers are very emphatic in warning against over-lubrication.

- (1) In the case of the Varidrive (speed range 2 : 1, 220 to 440 volts, type V.E., Serial 427,156, 3-phase, 900-1,800 r.p.m.), the supplier is so specific in his recommendations that it is advised to use only U.S. Viscogris No. 1. Lubricate at the several points noted on the attached motor plate every month. One of the motor bearings is a "Lubriflush," which is greased at the top of the bearing (location 1) after removing the bottom drain plug. After expelling the old grease with the new, allow the motor to run a few minutes before replacing drain plug. The company advises that it is important to run the Varidrive over its complete speed range at least three times a week. The Varibelt and Varidiscs are to be kept clean of lubricant; therefore, after greasing, wipe any

¹ Such as Andox B, Colonial.

excess from shaftings. It is advised to contact and contract with the local U.S. Electrical Motors office for regular inspection and maintenance of this unit.

- (2) The speed controller motor attached to the Varidrive is to be oiled every six months with a few drops of motor oil (S.A.E. 10) at the oil tube provided.
- (3) The G.E. Tachometer Generator (Type BC, 50 volts) is to be greased at both bearings every month.
- (4) The two hoist motors (G.E. Type K, 220 volts, Model SK43, AC 5398) are to be oiled every year with a few drops of motor oil. The load on these motors is intermittent.

(c) *Gear Boxes.*—The several gear cases are to be lubricated with either oil or grease as provided by the design. The grease shall be a light cup grease.¹ The oil shall be a steam cylinder oil which contains 5 per cent. of tallow.² The oil level is to be maintained at the levels indicated on the individual cases and not exceeded. In general, a slight temperature rise in the oil cases is permissible; excessive temperatures indicate a misalignment or over-lubrication. After one month of operation, the oil cases should be drained and refilled with fresh oil; this is repeated every year thereafter. The several grease cases should at the same time be regreased, expelling as much old grease as possible. If, of course, there is reason to think the oil level may have dropped in the oil cases, or the quantity of grease become scanty in the other cases, an inspection should show whether additional lubricant is required in the interim. The several points of lubrication are now itemized:

- (1) The twenty-six mitre gear boxes at the spool-banks (under main aluminium frame) are sparingly greased through the large plugs in the main frame. Never over-grease and never use oil in these cases. Of course, the lower gear boxes on the spool-banks are never oiled or greased.
- (2) The Cleveland Worm Gear (at the Varidrive output) (size 20 RT, Series 26, 1,750 r.p.m., ratio 15 to 1) is enclosed in an oil case. Refill at the plug. A drip pan is built under this unit.
- (3) The four Boston spiral mitres on the main drive (Cat. No. RC-SP) are in oil cases. Refill at the plug.
- (4) The two Boston reduction gears which are integral with the hoist motors are in oil cases. Since the duty of these units is so infrequent, it seems necessary merely to check the oil level yearly. Therefore, eliminate the oil changes advised for the other cases.
- (5) Three special gear boxes are built around the three hexagonal shafts. Grease at the plug. The hexagonal shafts are to be wiped clean and regreased at this time.
- (6) The four mitre gear boxes in the drying cabinet are greased by removing the top plate.
- (7) At the wind-ups the mitre and the bevel reduction gear boxes are to be greased at the plugs and removable plates.

In general, after the first month of machine operation, the operators should go over the whole assembly to tighten all fastenings, including those on the gear cases. An exception to this is the packing glands of the gear cases, which should be set in only a little more than hand-tight if required to prevent leakage.

The maintenance of the Nash Air Compressor, the Permutit water filter, and the Bryant Silica Gel Dehydrator is to be found in the instructions issued by these suppliers.

VIII. Safety Considerations

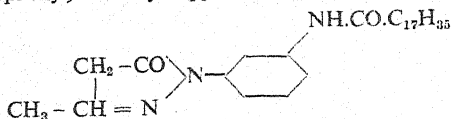
In the design and engineering of Machine 4C, much thought has been given toward the prevention of potential hazards to the machine operators. No turning shaft

¹ Such as No. 2 Castrolium, Colonial.

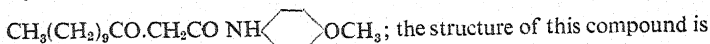
² Such as Cyclesso T-140, Colonial.

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2. 1(*m*-stearylaminophenyl) 3 methyl 5-pyrazolone



3. decanylamino acetic acid *p*-anisidide



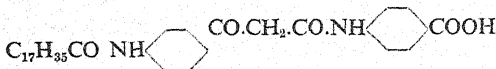
uncertain as the name given is open to different interpretations.

Other examples featuring a carbon chain of more than 5 carbon atoms are:—

p-lauryl aminobenzoylacetanilide



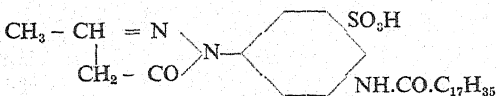
m-stearylaminobenzoylacetanilide *p*-carboxylic acid



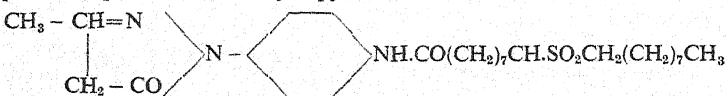
Examples combining both long chain and sulpho group are:—

1 (3-sulphophenyl) 3-(4-stearylaminophenyl) 5-pyrazolone

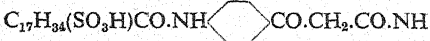
1(*m*-stearylaminophenyl) 3-methyl 5-pyrazolone (sulphonated)



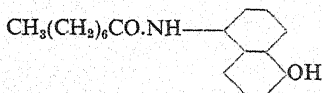
p-Oleic sulpho amino 3-methyl 5-pyrazolone



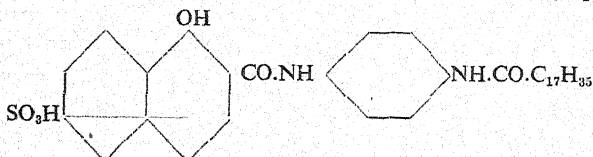
p-Sulphostearyl amino benzoyl acetanilide



5 caproylamino 1-oxynaphthalene



1 *p*-N stearyl 4N(1-oxy 2-naphthoyl)phenylenediamine (sulphonated)



The next application, B.P. 479,838 (Feb. 1938), deals with highly polymeric carboxylic acids and is, in fact, an extension to the principle of the previous patent. They are completely water soluble compounds and can therefore easily be distributed in the gelatine. It would appear that the substantivity is due to the existence of the coupler in the photographic layer in the form of a colloidal solution.

Suitable highly polymeric carboxylic substances are:—

Polyglucuronic acids $[\text{CHO}(\text{CH OH})_4 \text{COOH}]_n$.

Protein amino acids.

Poly-vinyl-carboxylic acids, *e.g.*, polyacrylic acid, mixed polymerisates with styrene, vinyl chloride or vinyl ethers.

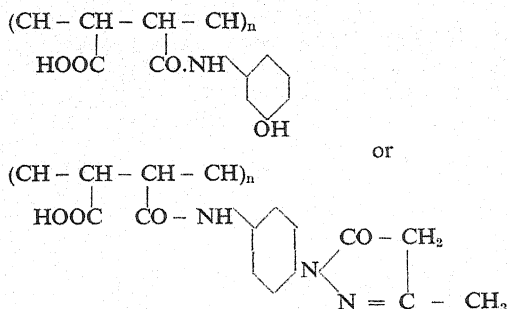
Polymerisates of maleic acid.

Polymerisates of fumaric acid.

Polymerisates of methylene malonic acid and mixed polymerisates of the last three named acids with vinyl compounds.

High molecular weight compounds from maleic acid anhydride or acetylene dicarboxylic acids prepared according to Diels Alder. These polycarboxylic acids are caused to react in form of their acid chlorides, anhydrides or esters with reactive groups attached to the colour former.

A condensation product from polyvinyl maleic acid anhydride and *m*-aminophenol or respectively 3-methyl 1-phenyl 5-pyrazolone would be



Another modification of the principle of the long carbon chain is given in **B.P. 483,000 (April 1938)**, which deals exclusively with carbohydrates as groups suitable for imparting the desired fastness to the emulsion. Several ways are described how to introduce such molecules to the colour component:

- (i) by esterifying or etherifying the carboxy group of the carbohydrate with the coupler,
- (ii) by the acide-amide combination,
- (iii) by forming a Schiff's base. This method has not been mentioned before and is probably used for such carbohydrates already containing a keto or aldehyde group.

The point is made that in choosing a carbohydrate, care should be taken to use one which is soluble in water or capable of swelling in it, *e.g.*, cellulose ethers, as described in D.R.P. 363,192.

This specification mentions for the first time the use of sodium salts of the described colour formers, which are said to be soluble in H_2O and for this reason to be easy to incorporate in the emulsion. Another remarkable feature is that a very heavy carbo-chain can be introduced in two stages by combining two carbohydrates together or only one carbohydrate with another similar long chain molecule. The following two examples will give a good illustration of what is meant.

Into the coupler a glucamine is introduced, which by itself would not make the compound fast to diffusion. This is then treated with a poly ethylenimine. On the other hand, a hydroxyl group of the carbohydrate can be esterified with a fatty acid, or a carbohydrate such as starch, dextrose or sugar, is treated with ethylene oxide according to D.R.P. 368,413. All the examples of colour-formers mentioned give blue-greens, such as derivatives of α -oxynaphthoic chlorides.

The next specification, B.P. 484,698 (May 1938), is rather similar to the previous. Claimed are Polypeptides, and the importance of this specification lies probably in the use of gelatine or its degradation product as an anti-diffusion group. As in the previous patent, the couplers given as examples of this claim for combination with colloids give blue-greens.

The claim largely comprises gelatine and its degradation product, albumens and Peptones.

Of a different character is B.P. 489,093 as it does not go back to B.P. 465,823 where aliphatic chain consisting of more than 5 carbon atoms was claimed. The anti-diffusion properties of the compounds in this new specification, the sterols, are probably due to their high molecular weight and complexity of structure. In the scope of this patent fall, Cholesterol, Bile acids, Cholic acids, etc. It is said that these groups, besides rendering the coupler fast to diffusion, have a favourable effect on the photographic emulsion by influencing the surface tension and enabling a better flow of the emulsion.

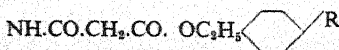
While in the former patents it has been proposed to make dyestuff components fast to diffusion by introducing a suitable group of aliphatic chain or cyclic character, there are claimed in B.P. 489,161 (July 1938) colour-formers having a chain-formed molecule in which the residue of a dyestuff component occurs as a colour-forming group several times periodically. Of the colour-formers especially suitable are those which are derivatives of benzene or naphthalene, having in para position to a hydroxy group either no substituent at all or a negative substituent such as, for instance, chlorine or a sulphonic acid group. These dyestuff formers are condensed under suitable conditions with aldehydes—for example, formaldehyde; from meta cresol and formaldehyde there are produced polydiphenyl-methane derivatives which contain the residue of the dyestuff component several times according to the size of the molecule.

The colour-formers thus obtained have the advantage that they possess a higher degree of dyeing capacity than have other colour-formers, since here the molecule has several positions for coupling components. It is further claimed that in this manner all the colours of the spectrum may be obtained, particularly the darker colour tints.

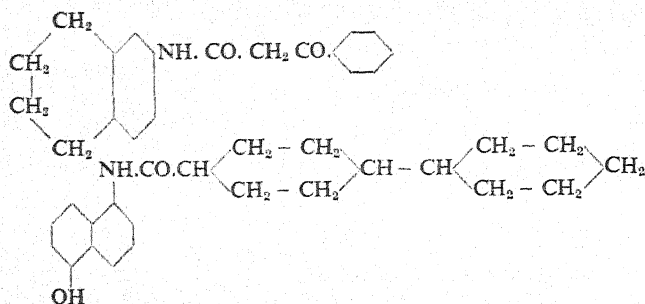
Claim 1 of the specification specifies colour-former having a chain formed molecule in which the residue of a dyestuff component occurs as a colour-forming group several times periodically. This claim is of a rather wide scale and probably the validity is very doubtful.

While all the previous specifications claim groups which do impart anti-diffusion, B.P. 489,164 (July 1938) differs from the previous ones, as no such group is claimed and has as its object the protection of a class of colour-formers into which can be easily introduced a group giving the desired properties, *e.g.*, those groups as specified in the previous applications. Another novelty is the first attempted definition of the term "fast to diffusion" which, according to this specification, is to be understood that when a dye coupler is added in the form of a solution or a dispersion to the photographic emulsion, it cannot be removed from a layer prepared with that emulsion, or can be removed therefrom only with difficulty by any solvent or dispersion medium which normally dissolves or disperses the coupler.

The class of colour-formers claimed are substituted amides of malonic acid where both —CO— groups of the malonic acid can be attached to the nitrogen atom or one only, and the other —CO— group may be part of a carboxylic acid, ester or amide group. It may be of interest to mention that Reindorp of Ilford Limited claims, in B.P. 518,017, a colour-former of the general formula



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One other specification, B.P. 468,946 (July 1937), occupies a rather special place, as it deals not with the actual groups giving fastness to the dye molecule, but with the use of such compounds containing them. It claims a process to produce multi-colour pictures without any developing operations in excess of those for normal black-and-white reversal development.

According to the specification, a multilayer film having incorporated in each emulsion layer a colour component fast to diffusion is exposed and developed in developer such as Amidol, which is not capable of forming a colour with the coupler; the silver is then bleached out and the residue halide fogged. The latent image is then transformed into colour positives simultaneously in all the layers by colour development and the deposited silver is then removed.

This patent is the actual fundamental basis of the Agfacolor process.

APPENDIX 4

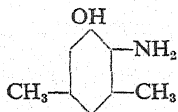
SURVEY OF KODAK AND RELATED PATENTS DEALING WITH THE PROBLEM OF THE ANTI-DIFFUSION PROPERTIES OF COLOUR- FORMERS UNTIL MARCH 1942

BEFORE proceeding with an individual study of those patents dealing exclusively with anti-diffusion properties of colour-formers in a photographic material, it might be worth while to deal first with a patent of a more general character.

B.P. 503,752 (April 1939). This is one of the most remarkable patents in colour photography ever applied for. Of forty-two pages, containing thirty-five claims, twenty-seven pages in tabular form are filled with the names of chemicals suitable either as couplers in themselves, or as intermediates for their preparation. The rest of the specification consists of a comprehensive treatise on colour photography which, however, is in a somewhat confused style.

From the wealth of information dispersed throughout some is certainly worth mentioning as it gives useful hints on anti-diffusion and colour coupling in general.

The rather interesting statement is made, that it is not easy to produce a brilliant lemon yellow component image in the upper layer with acetoacetic derivatives, since these derivatives couple quickly enough only in the presence of large amounts of alkali and the coupler, therefore, must be present in large excess in order to yield a good image; such conditions are actually ideal for increasing the diffusion of a colour-former. It is therefore proposed to use a developer which gives a yellow colour by direct oxidation simultaneously with reduction of the developable silver salts to silver, such as *o*-amino sym. *m*-Xylenol



The actual discovery made by the applicants was, that while it was known that azo components, in an insoluble form, were able to couple, under vigorous conditions, to give azo dyes, it was now found that indamine or azomethine dye formation could take place using an insoluble coupler in a photographic layer. Accordingly, there is claimed a process of a multilayer photographic material using "insoluble" colour couplers.

The novelty and justification of such a claim is questionable. Fischer, in his original paper, in the *Zeitschrift für wissenschaftliche Photographie*, has already pointed out that it would be necessary to have insoluble couplers in a tripack material to prevent the diffusion of the former from one layer to another. Furthermore, in an early patent of Agfa, B.P. 465,823, is claimed insoluble compounds containing long chain aliphatic groups giving anti-diffusion, as well as those which are specially made water and developer soluble.

The definition given for the term "insoluble," which is included in the claim, is rather unusual. "Insoluble" as defined in this specification means that the coupler is not more soluble than the most soluble of the following:—

Tri α -naphthol triazine,
 α -Naphthol 2-carboxylic acid α -(or β)-naphthylamide,
 α -Naphthol 4-benzoyl ketone and the hydrazone of the last named.

This definition, experience shows, is open to criticism.

Statements of interest appearing in the specification concern couplers in general and their uses. It is stated that coupling components containing a sulphonie acid or carboxylic group have strong substantivity to gelatine. On the other hand, aromatic hydroxyl and acid methylene groups do not confer upon the coupling components containing them, adequate affinity for gelatine on account of their extremely weak acid character. Halogenation brings about a certain affinity to gelatine only in very high molecular weight coupling components. Similarly, the substantivity of aliphatic, isocyclic or heterocyclic compounds containing the acid methylene group, is increased by the introduction of bromine into the methylene group, or of nitro groups into the nucleus.

The non-diffusibility of coupling components is determined, according to Schinzel, solely by the enlargement of the molecule and the resulting highly colloidal character. However, such a statement would appear too generalized, as some typically high molecular and highly colloidal azo dyes do diffuse, some even in spite of their sulphonie acid group.

In the case of α -naphthol and its 2 and 3 substitution products, a halogen, sulpho or carboxy group in the 4 position, is displaced in coupling development. Only if the 4 position is occupied by a non-displaceable residue such as alkyl, aryl or arylamine, does coupling take place in the 2 position, and any halogen, sulpho or carboxylic group in the 2 position is likewise displaced. The displacement of the acid radicals in the 4 position makes it possible to obtain completely insoluble indophenols from coupling components which are held substantively by the gelatine.

Another feature of this specification is the use of precipitating agents in the emulsion, and the use of salts of the coupler as defined in claims 6, 9, 10 and 11. Claim 6 specifies a coupling developer which is prepared with aliphatic amines, diamines, polyethylenamines or guanidines; while claims 9, 10 and 11 claim coupling components which consist of insoluble salts formed by the reaction between a high molecular weight coupling component of acid character, and a high molecular weight organic nitrogen base. Claim 10 is a specific example thereof, claiming a salt of a sulphonie acid derived from α -naphthol with quinine, cinchomine, diphenylguanidine or similar organic base, while claim 11 specifies a calcium, barium, magnesium, or lead or zinc salt of a coupling component of acid character.

Of the twenty-seven pages of tabulated chemical names it is sufficient to say that they comprise a fairly complete index of all the known families of aromatic organic chemistry. Tables I, II and II give easily prepared monovalent and polyvalent coupling compounds suitable for carrying out the invention. Table IV gives examples of high molecular coupling components and indicates their method of preparation from simpler coupling components. Table V gives examples of colour couplers which are made by condensing simpler components with high polymer compounds.

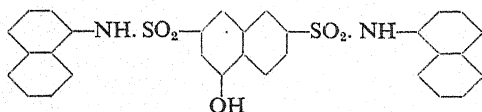
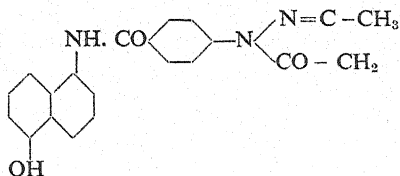
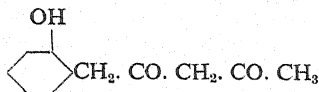
The validity of such a broad patent is very questionable and one might wonder for what reason it was filed by Schinzel for Kodak Limited. This specification is followed by a number of patents which have been divided out, namely, B.P. 503,814-822 inclusive.

B.P. 503,823 (April 1929) is similar to the Agfa specification B.P. 479,838 which describes a compound fast to diffusion, obtained by reacting a known colour-former with a highly polymeric carboxylic acid, or with a mixed polymerisate. Colour-formers which fall under the scope of this patent and which are fast to diffusion are obtained by condensing two or more molecules of a compound containing a coupling function with an aliphatic colloidal polyhydroxy compound such as a carbohydrate (see B.P. 483,000, I.G. Farben), for example, polyamylose, or a polyhydroxy compound such as cellulose (see B.P. 483,000, I.G. Farben), or a partially acylated cellulose or a polyvinyl alcohol (see B.P. 479,838, I.G. Farben). Alternatively, the coupling component may be obtained by combining two or more molecules of a

compound containing a coupling function and a polymerized compound such as one produced by polymerizing phenol (see B.P. 489,161, I.G. Farben). A coupling component, as claimed in this specification, can also be obtained by a similar combination with polyamines (see B.P. 484,698) or polymerisable hydroxy compounds.

B.P. 503,825 and 503,826 (April 1939). Both specifications are patents of addition to B.P. 503,752. Both deal with colour-formers which are insoluble as defined in the latter patent and which are, therefore, said to be fast to diffusion. The compounds claimed are not new, but there is a possible novelty in their molecular structure.

The first, B.P. 503,825, deals with colour components which have two different coupling functions in one molecule. This is best illustrated by three examples:—



The anti-diffusion properties of these compounds is probably due to their low solubility, and to the formation of large dye molecules, the first two of the examples coupling with two moles and the third with three moles of the developer. The hue obtained from such colour-formers containing mixed coupling functions would be of some interest. However, no reference to this occurs in the specification.

B.P. 503,826 is similar to the foregoing in that it does not disclose any new colour coupler, but with the difference that it claims part of the former to consist of a dye molecule or a leuco derivative. In this case the final dye is composed of the dye molecule and also of the dye formed by coupling. By the process of colour development the indamine formed is insoluble in caustic alkali, while the unchanged coupling component is removed by it.

The process is essentially that of elimination coupling described in B.P. 503,824 which uses a coupling component insoluble in the alkali used for the developer and removing the developer soluble coupling product. The residual component is then converted into a coloured image.

With B.P. 505,834 (May 1939), by M. Martinez, a new series of specifications issued by Kodak is started. As all these patents are based on that of Martinez it is necessary to describe it here in more detail.

This patent introduces a completely new idea in the localization of colour-formers to their appropriate layers. In all previous specifications colour-formers were claimed which have been made fast to diffusion by combining them with an organic residue of high molecular weight. In B.P. 489,274 such a residue, which in this case is a natural or synthetic resin, is described. According to B.P. 505,834 the colour-former is fixed in position by means of a natural or artificial (synthetic) resin or gum resin such as colophony, gum dammar or gum sandarach which is not chemically

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combined, but united with it in a purely physical way. The invention may be carried out by forming a solution of a resin and colour-former in a common solvent and precipitating therefrom a mixture of resin and colour-former "in intimate physical association with each other" but *not* combined.

The mixture of the colour-former and resin may be precipitated directly into a sensitive emulsion or into gelatine alone or other suitable colloid solution, and subsequently incorporated in a sensitive emulsion. It is claimed that resin and colour-formers are suspended in the emulsion in a fine discrete dispersion of particles in each of which is present both resin and colour-former.

The invention is based on the supposition that such a colour-former, being in intimate physical association with a resin, resists the action of the developer and thus is prevented from migrating to other layers, but is not prevented from colour coupling with the oxidation products of the developer acting on developable silver halide grains adjacent to the coupler-resin particle.

This principle of dye fixation has now been taken up by Kodak, who, as stated, have issued a large number of specifications based on this principle. The first of such patents is B.P. 524,154 (July 1940) (Kodak). There is no difference in principle between the foregoing Martinez specification and the Kodak one. However, it seems that Kodak have not only taken up the idea but have also worked out the practical application and so carried the invention a step forward.

The invention consists, according to Kodak, in providing a method of making a sensitive colour photographic element which comprises, on a single support, one or more layers consisting of differentially colour-sensitized emulsion of silver halides containing a colour coupler in a "water-insoluble, water-permeable" binder. The water-insoluble, water-permeable binder may be a cellulose ester such as cellulose nitrate or acetate. Other binders which can be used, are natural resins such as gum mastic, gum dammar, gum sandarach, or synthetic resins such as polystyrenes, polymethylacrylates, polyvinyl acetate or a coumarone-indene resin.

By replacing the term "water-insoluble, water-permeable" by "colour-formers in intimate physical contact with one of the binders," there is no noticeable difference between this and the Martinez specification. The only novelty left for Kodak to claim is the coinage of the term "water-insoluble, water-permeable binder."

The best results are said to be obtained by using water-immiscible solvents, as the use of water-miscible solvents, such as a lower alcohol, to assist in the incorporation, induces crystallization or wandering of the colour couplers, and also by using formers which are more soluble than 1:4-di(benzoylacetamino)benzene but less soluble than 2:4-dichloro 5-benzoylamino 1-naphthol, in an aqueous solution maintained at between pH 8.5-pH 11.

An interesting point is made with regard to the difficulty of penetration by the developer into binders, especially cellulosic binders, which is that a "porosity modifier" can be incorporated in the binder. The examples quoted are usually known as plasticizer or high boiling solvents for cellulose esters.

There are two patents of addition to this one, B.P. 524,554 and 524,555. The first claims the use of layers containing the binder in association with colour-formers, and the second the use of water-permeable cellulose derivatives in particular, as binding material.

A new idea is brought into the problem of anti-diffusion in B.P. 530,685 (Dec. 1940).

It has been found that colour couplers show very much less tendency to wander in acid solutions than in alkaline, and that if the emulsions containing them are so prepared, coated and processed that they are never subjected to liquid baths other than those which are of an acid character, until the coupling development has taken place, those colour couplers which will diffuse under alkaline conditions can nevertheless be used without undue diffusion taking place. Preferably the emulsion is maintained below pH 6.5, most desirably below pH 5.5 during incorporation, coating and preliminary processing.

An acid developer formula would be, as given by the specification:—

<i>p</i> -Diethylamine phenylendiamine HCl	..	..	20 g.
Sodium bisulphite	..	..	10 g.
Potassium bromide	..	..	2 g.
Water to make up to	..	..	1,000 c.c.

The film is immersed in the acid solution just long enough to wet it thoroughly, one minute being sufficient, and is then exposed for 5 minutes to ammonia vapour, when colour development takes place. The film is then washed in a liquid of sufficiently low pH value to avoid further colour development.

It is necessary to include in this survey of patents taken out by Kodak Limited, a patent which has been granted to Elliot and Sons, of Barnet. In patent of addition **B.P. 536,329 (May 1941)**, to **B.P. 505,834** of Martinez, the resins selected for use are the resinous reaction products of polybasic acids and polyhydric alcohols, variously described as phthalate or alkyl resins and also known under the registered trade mark of "Glyptals" and "Paralacs." Salts of such resins are not included in the claim.

It is stated that by employing such resins the depth and brilliance of the colour image is improved. The inventors do not claim the fixation of the colour-former in the binder (*e.g.*, gelatine), but by careful wording state that the diffusion of the colour-former is minimized to such a degree that it is possible to develop, in one and the same developer, layers containing different colour-formers without obtaining degraded colour images. The examples of uses given are similar to those of the Martinez patent.

Another Kodak patent running close to one of Agfa's is **B.P. 537,256 (June 1941)**.

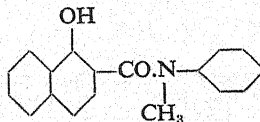
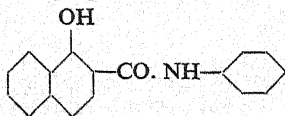
In **B.P. 484,698**, issued to I.G. Farben, colour-formers are claimed which have been made fast to diffusion by the introduction of one or more polypeptide or protein residues. In the examples given, gelatine has been singled out as being especially useful and advantageous.

In **B.P. 537,256** Kodak was allowed, by changing in some way the above claim, to justify the filing of this specification. The claim as put forward by Kodak reads: "A photographic material having at least one coating containing as binder an organic carboxyl or sulphonyl derivative of a protein which derivative dissolves in H₂O to give a solution which will gel on mere cooling."

The only difference between that claim and the Agfa one is that the Kodak claim is possibly even more general.

However, a difference in the preparation of such couplers (**B.P. 537,256**) is disclosed in the preamble. While Agfa, before it combined its coupler with the gelatine, boiled the gelatine for one hour with conc. acetic acid and so degraded it, Kodak managed to combine the colour-former without degradation of the gelatine, but by a very complicated procedure. The degradation effected by Agfa is apparently not for the purpose of obtaining a more suitable protein, but to effect the combination of colour-former and protein in an easy manner.

B.P. 538,914 (Aug. 1941). While there are described and known numerous colour-couplers containing the grouping —NH—CO— it has been found, according to the inventors, that the grouping —NH—CO— can be made more resistant to diffusion by replacing the hydrogen atom on the amide nitrogen atom by a monovalent organic group not containing solubilizing groups, *e.g.*, an alkyl or aralkyl, particularly a benzyl group. The explanation offered is that the hydrogen attached to the amide nitrogen atoms appears somewhat ionizable, while by replacing it with an organic radical no ionization could take place. It is still hard to see that a great difference in anti-diffusion properties could exist between the two compounds:—



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However, looking through the examples, one will observe that the hydrogen is usually substituted by groups which by themselves are said to impart anti-diffusion properties and are claimed by I.G. Farben in B.P. 465,823. (Carbon chains consisting of five or more carbon atoms.)

The claim is restricted to the derivatives of 1-naphthol 2-carboxylic acid and 1-naphthol 4-carboxylic acid.

It may be advantageous to consider now a patent which does not actually concern itself with the anti-diffusion properties of colour-formers, but deals with the fixation of dye bodies in the emulsion. In B.P. 540,365 (Oct. 1941), the dye body is incorporated in an auxiliary carrier which must be substantially insoluble in water and able to retain the dye body in a dissolved or dispersed condition. The nature and amount of the auxiliary carrier may be such that the fine particles of solution or dispersion of the dye body therein are liquid particles or solids or what is called a "liquid solution." By the term "liquid solution" probably is meant such crystalline materials which are capable of dissolving solid dye bodies by becoming liquid in that process. Such auxiliary carriers described, may be termed oil formers. They are usually liquids at ordinary temperature or low melting solids, and the most useful of them contains one or more polar groups such as halogen atoms, hydroxyl, carboxylic, amide or keto groups.

It would be expected that those auxiliary carriers or oil formers would differ from the water-soluble, water-permeable binders in that the developer, or any other solution in which this carrier is insoluble, could not diffuse through or affect the dye particle. But one of the specified requirements of those carriers is stated to be permeability to but insolubility in photographic processing solutions. The specification provides a list of substances which can be used as such auxiliary carriers. This list is added to in patent of addition B.P. 540,525.

B.P. 540,366 (Oct. 1941) deals exclusively with porosity modifiers as disclosed in B.P. 524,154. It includes a list of suitable high boiling solvents and plasticizer which can be used for that purpose.

B.P. 540,367 and 540,368 (Oct. 1941) are patents of addition to B.P. 524,154, and deal with the practical application of water-insoluble, water-permeable binders but add nothing to what has already been disclosed previously.

A rather ingenious idea forms the content of B.P. 540,563 (Oct. 1941).

It is common knowledge that by treating gelatine with an aldehyde such as formaldehyde the gelatine is hardened. This is probably due to a chemical reaction taking place similar to the formation of Schiff's bases. According to this invention a compound is incorporated in the emulsion, having two carboxyl groups (*e.g.*, dialdehydes, diketones) together with a colour-coupler having a free amino group. When such a coupler and the compound containing the carboxyl group are mixed with the emulsion, one carboxyl group of the said compound reacts chemically with the amino group of the coupler and the other carboxyl group reacts with the amino group of the protein (gelatine), thus combining the coupler with it. The amino group of the coupler, which reacts, is preferably a primary amino group, but other amines may be used. Glyoxal, diacetyl or terephthaldehyde are suitable carboxyl compounds. Hardening of the gelatine alone by glyoxal does not prevent diffusion of a coupler without a free amino group.

Another difficulty encountered by using colour-couplers associated with a water-insoluble, water-permeable binder is dealt with in B.P. 541,589 (Dec. 1941).

Processing baths sometimes do not act to a sufficient extent or sufficiently rapidly upon the colour-couplers dispersed; often very weak and sometimes no colour at all is produced. It is known that dispersed liquid colour-formers of low solubility are more amenable to processing baths than are solid particles of colour-couplers. However, the number of such couplers is very small.

The inventors of this patent have now found that colour-couplers, which are solids under ordinary conditions, can be converted into liquids of oil consistency by the

addition of certain high boiling organic compounds which are insoluble or only very slightly soluble in water and in the wet photographic emulsion. In this way colour-couplers are maintained in liquid solution in the emulsion. (See B.P. 540,365.) Such organic compounds which are capable of forming liquid solutions are termed "oil-formers." In order to obtain a good dispersion, emulsifying agents are suggested such as "Gardinol" (registered trade mark) or "Arctic Syntex T."

A very exhaustive list is supplied of colour-couplers suitable for use with the present invention. All 46 couplers which are suggested contain some group which has been claimed, in one or another specification, as imparting anti-diffusion to the colour-coupler molecule. This suggests that the non-diffusion of the coupler to other layers is not so perfect as it is claimed when dispersed in the described fashion.

The interesting disclosure is made, that a number of oil formers possess the rather surprising property of causing a shift in the absorption of the dyes formed during colour development.

It is necessary to consider again a Martinez patent, namely B.P. 543,606 (March 1942), which follows directly on his last B.P. 505,834 and which has become subsequently the parent patent for all the following applications claiming protective colour coupling processes.

Apparently the localization of the colour-formers by means of resins does not completely solve the problem of diffused pictures. On closer examination each point of image is represented by a circle enclosing the area of diffusion. The "localized" particles apparently are acted upon by oxidized developer diffusing into them from the outside, that is, from the various silver halide grains situated all around them over some finite area producing, therefore, a circle of image diffusion.

This is achieved by the precipitation of the silver salt in the presence of a resin and a water solution of the photographic binder such as gelatine. Some substances, especially if soluble in alcohol or other volatile solvents, may be admixed immediately after the precipitation of the silver halide, before the resin particles are fully formed, and thereby become incorporated during the growth in the subsequent ripening.

As far as novelty is concerned the patent is simply an "improvement" on his previous one. However, the specification contains a large amount of useful descriptive examples, which are an application of both patents.

B.P. 544,064 (March 1942). This is actually a patent of selection from B.P. 524,154, even if not stated as such.

The coupler is dispersed in an alkaline emulsion with polyvinyl phthalate or cellulose acetate phthalate. These substances appear to have a high solvent action on the colour-former, which seems to cause them to become strongly associated physically but not combined chemically, and on account of their own relative high molecular weight they show little tendency to diffuse through the alkaline gelatine, although they are completely miscible with alkaline gelatine solutions.

Elliot and Sons, in B.P. 526,329, selected special resins such as glyptals or paralacs to obtain dispersion of colour-formers in the emulsion. It might be remembered that it was then specially pointed out in this report that salts of such resins were not included in the invention.

In the patent issued to Kodak, B.P. 544,134 (March 1942), it is stated that the tendency of a dyestuff or colour-former to diffuse can be reduced by adding to the emulsion, while still in liquid state (*i.e.*, before coating), a water-soluble salt of a resin or a water-insoluble metal salt of a resin. The invention can thus be carried out (a) by adding a water-soluble salt of a resin to the emulsion, (b) by adding a water-insoluble metal salt of a resin to the emulsion, or (c) by adding to the emulsion both a water-soluble salt of a resin and a water-soluble metal compound which will react with the resin salt to form a water-insoluble resin salt.

In all these three cases the result obtained is probably the same as there is obtained, dispersed in the emulsion, a water-insoluble metal salt of a resin.

The resin salt can be one of a natural or synthetic resin, for instance, shellac,

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collophoxy, gum mastic, dammar, sandarach, or a glyptal resin. In case of a water-insoluble salt of a resin, the following metal salts can be used:—

Magnesium	Cadmium	Cobalt
Calcium	Manganese	Copper
Strontium	Zinc	Thorium
Barium	Cerium	
Aluminium	Nickel	

As it can be seen, the alkali metals such as Na, K and Li are not included in the list. The reason can be found in the disclaimer given of B.P. 541,558, issued to Du Pont in Dec. 1941, which claims the use of water-soluble salts of alkyd resins.

In a patent of addition B.P. 544,135 (March 1942), insoluble salts of resins are claimed besides those of certain metals, *i.e.*, those of organic bases of complex structure or high molecular weight such as quinine or cinchonine. A special point is made that it is only the resin which forms an insoluble salt and not the dye-forming substance.

More "water-insoluble, water-permeable" binding agents are claimed in B.P. 555,728 (Sept. 1943). They are hydrolyzed natural resins, resin esters, ethers or ether esters formed with organic or inorganic acids or alcohols. The hydrolyzed natural resins can be used in the form of their salts, either water-soluble or water-insoluble. The invention does not, however, include the use of salts of hydrolyzed lacs.

Among the advantages claimed by the use of such substances are:—

1. Formation of a finer dispersion than the parent resin.
2. Increased capacity for dissolving the dye-forming substance.
3. Adjustment of the degree of hydrolysis of the resins, by using suitable acids or alcohols for esterification or etherification, products of the refractive index of gelatine can be obtained, thus eliminating light scatter and matte surfaces when gelatine is employed as the carrier.

Specifications reviewed

I.G.'s	458,400	483,000	489,161	491,958
	465,823	484,698	489,164	491,959
	479,838	489,093	489,274	
Kodak's	503,752	527,493	540,368	544,064
	503,814-826	530,685	540,525	544,134
	505,834	536,329	540,563	544,135
	512,752	537,256	540,667	555,728
	524,154	538,914	541,558	
	524,554	540,365	541,589	
	524,555	540,366	543,606	

APPENDIX 5

NOTES ON THE USE OF ANSCO COLOR CAMERA FILM TYPE 735

I. Colour Balance

Type 735 is balanced for daylight quality illumination, *i.e.*, for sunlight between two hours after sunrise and two hours before sunset, or artificial daylight sources, such as the commonly used arc lamps of 5,400°K. colour temperature.

II. Film Speed

A. *ASA Exposure Index No. 6* (Tentative).

B. Suggested ratings by the older Weston and G.E. systems:

Weston	..	5
G.E.	..	8

C. When using *Ansco Color Daylight Conversion Filter 10* on the camera lens, the effective film speed is reduced by two stops. It is suggested that the conversion filter should be used on both the exposure meter and the lens in order to read the effective illumination.

III. Lens Filters Recommended

A. *Ansco Conversion Filter 10* converts 3,200°K. tungsten illumination to daylight quality.

B. It is recommended that haze filters be used on all interior and exterior photography with Type 735. The *Ansco UV-15* or *UV-16* is suitable, as is also the *Wratten 114A*. With heavier haze conditions the *Ansco UV-16*, *UV-17* or *UV-18* filters may be used, the higher numbers giving heavier cuts in the visible blue-violet.

IV. Lighting

The lighting required for best results is representative of that practised in modern colour photography. Somewhat softer lighting contrast than that normally employed in exposing black and white negatives is advisable. Colour reproduction provides tone modulations and rendition of detail that might ordinarily be achieved through lighting in black and white photography. A suitable ratio of key light to fill light is 2:0; this ratio should not exceed 4:0. Rim light is helpful in giving relief and roundness.

Light Sources in representative combinations:

A. Exteriors:

Key: Sunlight.

Note: A neutral white scrim may be used to good advantage with sunlight to soften the shadows on close-ups.

Fill: (a) High-intensity arc spot lamps, with Y-1 filters.

(b) Neutral white reflectors, preferably with diffuse or semi-diffuse surfaces.

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B. Interiors:

Key: High-intensity arc lamps, with Y-1 filters.

Fill: White flame arc broads, such as *Duarc*s, and or *CP* lamps filtered with Macbeth *Whiterlite* filters. It is recommended that arc broads be used for the principal fill.

V. Make-up

Natural street make-up with dark red or blue-red lipstick is preferred. The lipstick or rouge should consist of very pure red without any orange or yellow hue, and may be mixed with various degrees of blue to achieve the darkness desired. In general it is desirable to avoid make-up preparations that contain a predominance of brown or yellow, as well as those of purplish or grey hue.

Note: Tests should be made on individual artists to determine the optimum make-up combination with the materials used.

VI. Set and Costume Colours

To ensure the most satisfactory results in colour rendition, the colours intended for production use in sets, wardrobe materials and animation should be pre-tested under representative lighting conditions. Those hues and colour tones which are reproduced to best advantage may then be selected by viewing prints of the test. Attention to good colour composition in each scene will, of course, enhance the screen results.

VII. Darkroom handling

Unwrapped Type 735 stock should be handled in total darkness only, particularly when being wound on a rewinder. Even dark green negative safelights may cause colour fog.

VIII. Original Image Characteristics on Type 735

The normal image has soft gradation and is appreciably darker than a projection transparency. The colour balance in the lighter densities will be somewhat bluish. Proper exposure will produce the following visual densities:

Highlights	.. ..	D.0.80—1.00
Black (Photographed)	..	D.2.2—2.5

The maximum density in an unexposed area will usually be in the range 2.6-2.8.

IX. Production End Tests

At the end of each scene or sequence representing a set-up or condition of lighting, a typical scene and cast exposure should be made, with an *Anso Color Chart* suitably placed to occupy up to $\frac{1}{4}$ of the frame. Approximately 10 ft. of a like test should be included at the end of each roll for processing tests. Also, a full frame 10 ft. take of the chart is desirable on each day's shooting of a picture.

APPENDIX 6

PROCESSING CONTROL PROCEDURES FOR ANSCO COLOR FILM*

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AnSCO, Binghamton, New York

*Re-printed by kind permission of the Society of Motion
Picture Engineers, U.S.A., and Ansco, Binghamton, New
York*

Summary—Reproducible processing of Ansco color film requires continuous control of the solution compositions. Early experience showed that frequent change of processing solutions was necessary to maintain consistency. New replenisher formulas are described which together with sensitometric controls and occasional chemical analysis have proved successful for maintaining the processing solutions in a satisfactory condition indefinitely. Color-balance differences resulting from varied types of agitation, depending on the processing equipment, may be adjusted by changing the chemical constitution of the first developer.

THE continuous processing of Ansco color film requires control of speed, gradation, fog, D-max., and other variables common to the processing of black-and-white films, but with the complicating factor that these variables must be kept constant in each of three superimposed emulsion layers.

When this color film was first introduced, frequent changes of processing solutions were advised to prevent the deteriorating effects of aging and exhaustion. With experience, methods of processing control gradually have evolved using continuous replenishing procedures controlled by sensitometric and analytical tests. This paper presents an outline of the essential control steps necessary at each operating stage of a processing laboratory. Through the use of these practices an experienced control man can maintain a set of processing solutions indefinitely. Tests are outlined not only for actual machine operations but also to check raw chemicals and individual mixes of solutions. Although essentially designed for motion picture laboratories, the basic methods are also applicable to roll- and sheet-film processing units, and with different developer replenishers, to the processing of Printon.

I. Basic Control Methods

Three general control methods, photographic, analytical and pH, are recommended for the various testing operations. The necessary tests are outlined briefly in Fig. 1. For simple solutions such as short stop and hardener, simple pH tests suffice. For developer solutions and actual machine controls, both photographic and analytical tests are necessary. A chemical standard is used as the basis for all tests. A supply of high-purity chemicals should be maintained as the processing standards and type solutions should be prepared from these chemicals with accurate mixing.

A. pH Tests

pH is controlled with Coleman or Beckman Laboratory Model pH instruments using glass-calomel electrode systems. Other instruments of equal sensitivity would suffice. All pH readings including those of developers given in the paper are based on the use of a normal glass electrode. It is recognized that the use of an electrode introduces sodium ion errors due to the high salt concentration of the solution, but in practice, since the salt concentration remains constant, consistent and useful

* Presented May 18, 1948, at the SMPE Convention in Santa Monica.

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readings are obtained and no attempt is made to correct the data. If a special electrode designed for high salt concentrations at a high pH (10 to 11) is used, the developer pH readings will range about 0.10 higher than indicated in this paper. It is to be emphasized that except for short stop and hardener solutions which are fully controlled by pH, the pH values are used merely as a guide. Solutions can be rejected and trouble located if pH measurements fall outside normal limits, but proper pH does not ensure satisfactory performance.

B. Photographic Tests

These can be divided into two parts: (1) photographic solution control tests, and (2) photographic tests made on the machine during operation.

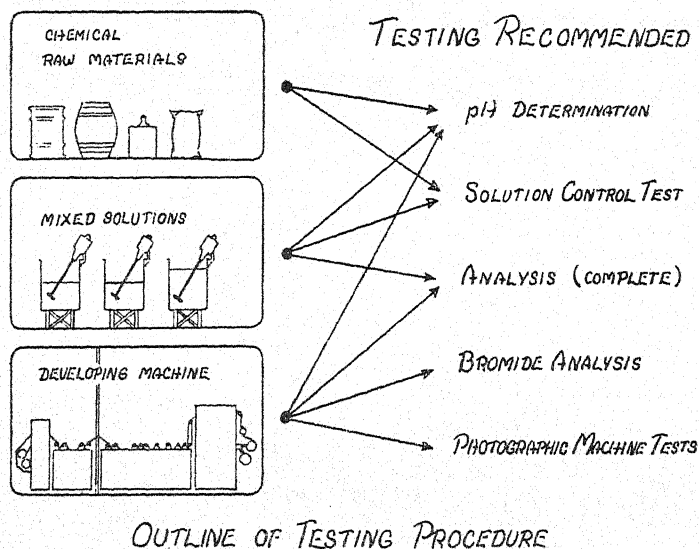


FIG. 1

1. Photographic Solution Control Tests

Tests so termed are used for testing raw materials, solution mixes, and in locating possible sources of trouble with machine solutions. The photographic test consists simply in processing duplicate sensitometric strips of color film through the standard cycle of color-film processing except that the strips are separated at the solution to be tested and one strip run through the sample solution and one through the type solution. These sensitometric strips should be exposed on the same type of color emulsion the machine will process. A supply of film of a single emulsion number sufficient for several months' control operation should be set aside to avoid too frequent typing in of emulsions. Either time or intensity-scale sensitometry may be used, although intensity-scale instruments are recommended because they give a more accurate indication of a film's practical performance. The instrument, however, must be capable of highly reproducible results and should be adjusted to produce a color balance close to neutral. Both visual and densitometer measurements are more accurate when made with neutrally exposed film. Latent-image changes in exposed strips are normally of small magnitude. However, it is recommended for

optimum consistency that no exposures more than two months old be used for control work.

It is essential that solution testing be done under carefully controlled conditions of agitation, time, and temperature so that the system itself has reproducibility greater than the solution tolerance to be tested. In practice it is possible to construct apparatus that will give results deviating by not more than $\frac{1}{8}$ stop speed or $\frac{1}{16}$ stop color balance when identical solutions are used for type and sample. This degree of reproducibility requires mechanical agitation, water baths for solution temperature control, and methods of quickly changing film from solution to solution. In the Ansco laboratory, an apparatus has been constructed employing a series of stainless-steel tubes each holding $1\frac{1}{2}$ litres of solution (Figs. 2 and 3). Special racks each holding two 35-mm. strips in a film slide-type holder fit into the tubes. A rubbered vane, with a vertical movement operated by a series of pulleys over the tubes, is

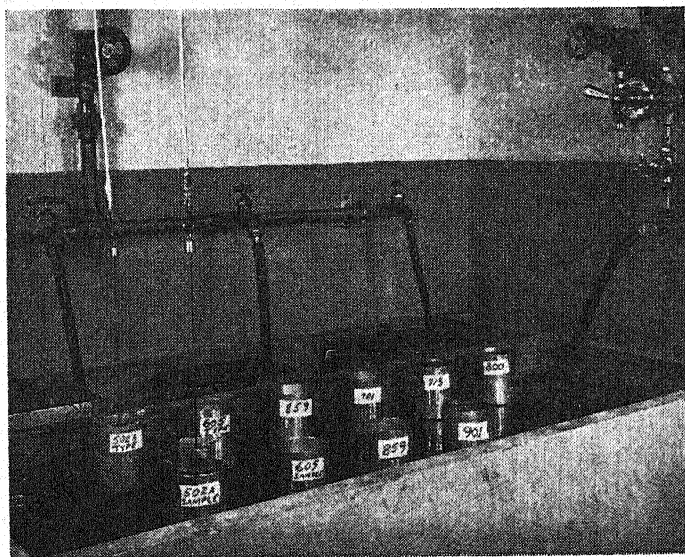


FIG. 2

built into each rack. The whole unit is set into a water bath with temperature control. It is not necessary to employ exactly this design of apparatus, but mechanical agitation is strongly recommended.

Photographic solution control tests are interpreted by reading the color densities of the type and sample sensitometric strips on an Ansco color densitometer¹ and comparing the plotted results for speed, density, and color-balance differences. Acceptable tolerances in processing solutions necessarily are high, but specific acceptable limits must depend somewhat on circumstances. In general, solutions can be accepted that do not give speed differences greater than $\frac{1}{4}$ stop or color-balance differences greater than $\frac{1}{8}$ stop from type. Should an occasion arise where both the first developer and color developer or their respective replenishers show $\frac{1}{8}$ stop color-balance difference, both in the same direction, the combination obviously would produce an intolerable result on the machine.

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Normal machine-processing times are recommended for the solution control test machine except replenisher solutions are tested with two-thirds the developing time of their basic solutions. It is desirable, although not absolutely necessary, that the solution control test machine and the processing machine turn out closely matched results. Often differences in agitation will make this difficult. The procedure for chemically adjusting color balance described in the section on machine adjustments would not be applicable in this case because it is necessary that the solution control machine operate to test the exact machine formulas.

2. *Photographic Tests of Machine Operation*

The basic purpose behind all preliminary testing is, of course, to control the actual developing machine. To this end the greatest reliance is placed on photographic controls because these indicate directly the results the machine is producing. Test

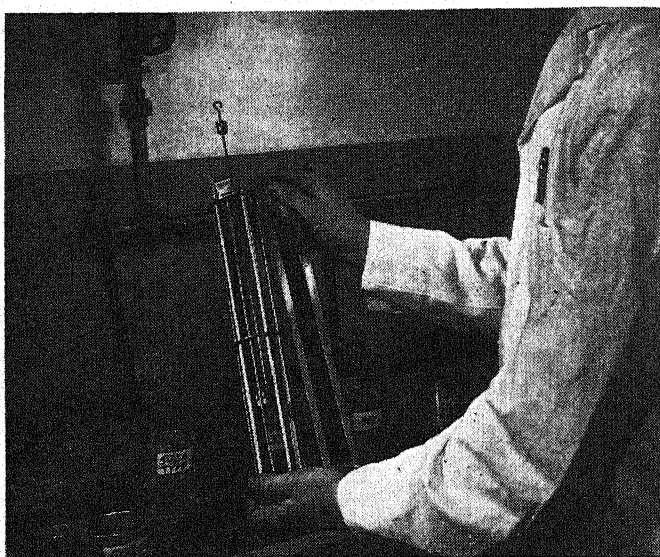


FIG. 3

strips are run through at 15- to 30-minute intervals. As the strips come off the machine, they are quickly compared visually with the preceding strips and the color densities of three representative toe, middletone, and shoulder steps read and plotted as shown in Fig. 4. The control chart that gradually accumulates as a result of plotting these continuous strips is of great value in controlling the machine. By connecting the points as the graph is constructed, a running record is obtained of the speed and color-balance fluctuations. Speed increases in reversible film are denoted by a drop in all layer densities, a speed decrease by a rise in all densities, while color-balance shifts are denoted by unequal changes in the various layer densities.

As can be seen from Fig. 4, minor fluctuations in over-all speed and very slight deviations in color balance occur between successive developments. These fluctuations are normal in the best regulated machines made to date and are caused by a variety of effects all minor in character but which add up to measurable differences.

The variables which cannot be absolutely controlled include slight differences in

film emulsions, film exposures, chemicals, solution mixes, developing times and temperatures, circulation rates, drying conditions, and even final densitometry. These additive deviations may amount to as much as plus or minus $\frac{1}{4}$ stop speed variation as well as color-balance shifts of plus or minus $\frac{1}{2}$ stop. It is the controlman's responsibility to distinguish between a fluctuation that is within the optimum operating capability of his apparatus and a deviation that represents improper control. For this reason, graphical methods are employed. By following such a graph, it is possible to control the machine output within narrow limits. Fig. 5 illustrates another series of developments; it can be seen that for developments *A* through *B* fluctuations ranged upward and downward in a fairly regular pattern. This was normal machine operation. Beginning with *B*, although the fluctuations were still up and down, the

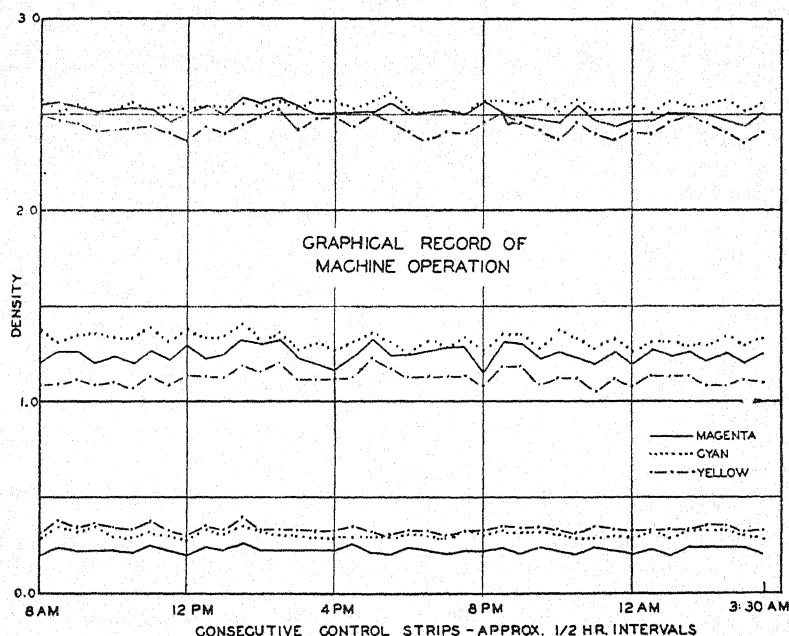


FIG. 4

majority was running higher than normal in density. This to the controlman indicated a definite trend toward lower speed that would require corrective measures. Since this rise was accompanied by a slight gain in the magenta and yellow density over the cyan layer in the middletone region (density 1.2) and also in the shoulder densities, he increased the replenishment rate of the first developer by 10%. As can be seen by *C'* to *D* (film *C* to *C'* had passed through the first developer before the correction could be applied), this change of replenishment rate achieved the desired result as the speed increased and the colour balance became more neutral.

In case of questionable deviations in the graph, complete sensitometric curves should be plotted for the trips involved. For general purposes, the three-step plot will suffice.

Many machine operators will prefer to run a pictorial type in addition to the sensitometric type, since this gives them a clearer picture of the actual effect of machine

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differences on picture quality. The interpretation of pictorial strips should, of course, be given secondary emphasis as compared to the more accurate, numerical interpretation of the sensitometric control strips.

When deviations occur in the machine photographic tests, it is advisable to run a chemical analysis immediately to fix the cause of the deviation. Photographic side tests also may be made by using the solution control machine to compare a solution withdrawn from a machine tank with a type solution. Provided proper pre-checking of solutions is made at the time of mixing, no serious deviations ever should occur. Such differences as do occur will normally arise from an excessive amount of high or low key film exposures, or from excessive aeration of solution due to leaky circulation pumps or from the aging of unused solutions.

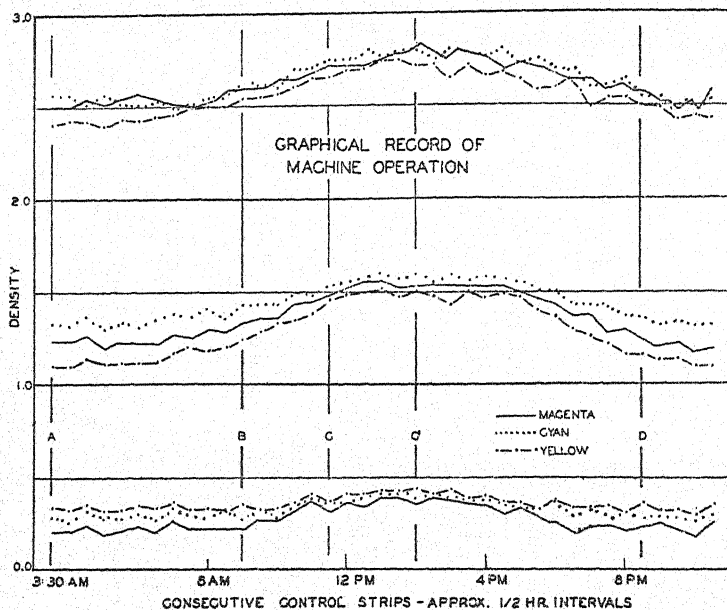


FIG. 5

C. Analytical Controls

The analysis procedure for the developer and bleach solutions is outlined in the paper by Brunner, Means, and Zappert.² For routine machine operation, complete developer analysis should be run approximately every 48 hours. Bromide analysis of developers should be run every 4 to 8 hours as changes in bromide concentration are an accurate indication of improper replenishment rate. Bleach titrations should be run at 8-hour intervals. The condition of the bleach can be judged roughly by visually noting the time required for the bleach to etch out the silver antihalo layer. Bleach performance is generally satisfactory if this takes place in one-third the total bleaching time. It should never exceed one-half the total bleaching time.

The fixer tank should be analyzed for silver content at intervals of 8 hours of machine operations. Fixer performance is satisfactory if time of clearing does not exceed one-half total time of fixing.

II. Machine Control and Replenishment Data

Successful replenishment can be carried out on any type of equipment having fully controlled and reproducible temperature and agitation conditions. Within the Ansco plant, the system has been adapted to machines used for 16-mm. film processing as described by Forrest,³ for 35-mm. film processing as described by Harsh and Schadlich,⁴ and for rack-type sheet-film processing machines varying from a large Pako machine to small vane-agitated 3½-gallon tanks. The value of replenishment is questionable for hand-agitation systems. The greatest control normally is obtained with the larger size machines that are in constant rather than intermittent use. It is desirable to maintain continuous filtration systems in both color and first-developer tanks as the build-up of gelatin particles, specks of oxidized developer, and other foreign material hasten the chemical breakdown of solutions. Proper filtration will keep both first developer and color developer clear and light in color after months of operation.

A. Modification of Processing Solutions to Change Colour Balance

The widely varying agitation conditions existing in the different types of processing equipment introduce a complicating factor because variations in agitation can produce different color balances. Partial compensation for these balance differences can be obtained by increasing or decreasing developing times. However, in order to achieve the closest possible matches in speed, gradation, and color balance, it is sometimes necessary to make slight chemical changes in the processing solutions themselves.

The most convenient tools for modifying color-balance differences resulting from different agitation conditions are variations of the thiocyanate and iodide concentrations in the first developer solution. Chemical analysis of No. 502 first developer has shown that iodide accumulates during film development, and, depending somewhat on the type of film processed, exposure level and volume of replenisher added, normally reaches an equilibrium of from 3 to 6 mgm. per litre of developer. Iodide-analysis methods and a discussion of iodide equilibrium for black-and-white film developers were given by Evans, Hanson, and Glasoe.^{5, 6}

Practical tests with color film show that even a small concentration of iodide exerts an appreciable restraining effect on the yellow and magenta layers giving an effective speed loss in these layers and a shift in the over-all color balance toward the brown. It can be shown that accumulation of iodide is responsible for a large part of the color-balance shifts that occur when a first developer is used. If small amounts of potassium iodide are added initially to the fresh developer, the color-balance changes are reduced. We have adopted the practice of adding small quantities of potassium iodide to fresh No. 502 first developer. No iodide is added to the replenisher solution.

Under processing conditions where only moderate agitation is encountered (as in Pako processing) bluish-cyan color balances are often encountered because the first developer is most active on the top layers of the film and does not easily penetrate to the bottom layer. Increased first development times under such conditions do not change the relative rates of development in the layers. However, the maintenance of a higher than normal iodide concentration will restrain first development in the top layers more than in the cyan layer, and by use of slightly longer than normal developing times a normal color balance can be achieved. In this case, it is necessary to maintain this high iodide concentration by adding a small amount to the replenisher solution.

The above color-balance shifts are essential for the processing of Types 234, 634, 235, and 635 sheet, roll, and 35-mm. cartridge films, since these materials must be balanced so they can be processed successfully both by amateurs with hand-processing

outfits and by factory finishing. Obviously it is not necessary to achieve a so-called normal balance for a machine used to process a printing-type film whose balance is normally modified by printing filters, but it is of course essential that whatever balance is obtained be maintained consistently.

B. Replenishment Procedure

1. General

The following developer replenishers were worked out using the solution analysis technique described by Brunner, Means, and Zappert.² Although the exact replenishment rates may require adjustment from time to time, use of the replenishers will maintain the solution ingredients very close to their initial concentrations.

Greater than 10% variation in replenishment rates rarely is necessary. Trends that are not corrected by such changes eventually are traced to a mechanical or physical fault. Such difficulties should be solved by chemical analysis of the solutions in doubt. Through the knowledge of the film response to different chemical variations, skilled controlmen have maintained consistent color balances and speed over months of operation. The exact effects produced by photographic variations differ somewhat among different emulsions depending on the exact color balance of the emulsion. In general, variations of color developer affect the heavier densities to a greater degree than the lower densities, whereas variations in first developer cause deviations in the over-all speed and balance of the film.

Relatively large quantities of replenishers are utilized in most cases. In the first developer, the rate is high to avoid build-up of bromide in the developer. In the color developer, replenishment rate is high because the replenisher solution is nearly as concentrated as possible. Bromide accumulates so slowly in the color developer it is necessary to add it in the replenisher solution to maintain the original amount. The short stop and hardener solutions are replenished at these high rates to prevent excessive accumulation of contaminants. No continuous replenishment is used with the bleach and fixing baths. The bleach is shifted to a separate tank, rejuvenated with bromine, and after adding additional salts to make up for those lost by dilution, is returned to the machine tank. The fixer is used to exhaustion, then dumped into a large crock for sulphide recovery of silver.

2. Detailed Replenishment Procedure

The replenishment rates given in this paper are based on the rates used for the Ansco 16-mm. and 35-mm. developing machines. Other machines may perform best with slightly modified conditions or formulas. In fact, replenishment rates normally vary slightly during routine operation of any single machine. However, the formulas and rates of replenishment listed provide a close approximation of the requirements of any machine and are to be recommended as a starting-point.

The developer replenishers were formulated using solution-analysis techniques and when used in combination with photographic and analysis tests have maintained developers over periods of months in the Ansco laboratories.

It is recommended that 3.5 to 5.0 mgm. per litre of potassium iodide be added to fresh tanks of No. 502 first developer. Analysis data indicate that the normal iodide-equilibrium ranges around these figures, subject somewhat to the exposure level of the film processed.

Changes in first developer activity are evidenced by over-all speed changes of the complete film. The exact color-balance differences obtained by increased or decreased amounts of first development vary slightly from film to film, but generally increases of first development show up as reduced magenta density in the balance.

This solution is replenished at a rate necessary to maintain a pH of 5.0 to 5.5. The

TABLE 1.—FIRST DEVELOPER REPLENISHMENT

	<i>No. 502 First Developer.</i>	<i>No. 502 R-3 First Developer Replenisher.</i>
Calgon	1 gm.	1.0 gm.
Metol	3	3.2
Sodium Sulphite	50	50.0
Hydroquinone	6	7.5
Sodium Carbonate	40	40.0
Potassium Bromide	2	—
Sodium Thiocyanate	2	2.4
Sodium Hydroxide	—	1.1
Water to make	1 litre	1 litre

Basic replenishment rate—23 c.c./ft. 35-mm. film

TABLE 2.—SHORT STOP REPLENISHMENT

	<i>No. 859 Short Stop.</i>	<i>No. 858 Short Stop (Replenisher for No. 859).</i>
Glacial Acetic Acid	5 c.c.	10 c.c.
Sodium Acetate	30 gm.	20 gm.
Water to make	1 litre	1 litre

pH fresh 5.20-5.30 *pH* fresh 4.70-4.80

Basic replenishment rate—24 c.c./ft. 35-mm. film

volume of replenisher is great enough to provide sufficient solution change to prevent accumulation of excessive developer solution. If the short stop *pH* is maintained at a higher *pH* than 5.5, increased hardening will result from the No. 901 hardener, but reduced short stopping action and scumming will be obtained. A *pH* lower than 5.0 produces less hardening by the No. 901 hardener and a *pH* lower than 4.5 may give difficulty with film blistering.

TABLE 3.—HARDENER REPLENISHMENT

(These statements apply to the solution used after either first or color developer)

	<i>No. 901 Hardener.</i>	<i>No. 901 Replenisher.</i>
Potassium Chrome Alum	30 gm.	30 gm.
Water to make	1 litre	1 litre

Basic replenishment rate—30 c.c./ft. 35-mm. film

This solution is replenished with the same solution as the original at a rate necessary to keep the tank *pH* approximately 3.5 to 4.0. If the *pH* rises above 4.5 (although the hardening effect will increase up to a *pH* of about 5.0) chrome alum sludge and scum may also result. If the *pH* falls below 3.5, reduced hardening is obtained. Since a solution of chrome alum will hydrolyze on standing, the subsequent release of acid causes a natural drop of *pH*. The carry-over of a small quantity of alkali is not undesirable because it aids in maintaining the optimum *pH*.

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TABLE 4.—COLOR DEVELOPER REPLENISHMENT

	<i>A-605 Color Developer.</i>	<i>A-605 R-2 Color Developer Replenisher.</i>
Calgon	1.0 gm.	1.0 gm.
Sodium Bisulphite	2.0	2.3
S-3	4.0	5.6
Sodium Carbonate	67.5	80.0
Potassium Bromide	1.0	0.6
Water to make	1 litre	1 litre

Basic replenishment rate—23 c.c./ft. 35-mm. film

Use of this replenisher, like the first developer replenisher, is designed to maintain the original concentration of developer ingredients. Regular bromide analysis will assist in maintaining the proper replenishment rate. No iodide is added to this bath. Analysis indicates some iodide is accumulated during use, but the formula is relatively insensitive to this restrainer in the quantities involved.

TABLE 5.—BLEACH REPLENISHMENT

No. 713 Bleach.

Mono Sodium Dibasic Potassium Ferricyanide	100 gm.
Potassium Bromide	15
Dibasic Sodium Phosphate	40
Sodium Bisulphate	25
Water to make	1 litre

It is recommended that No. 713 bleach be rejuvenated intermittently with bromine additions.

During normal bleaching operations, bleach exhaustion is caused by depletion of ferricyanide and bromide ions as well as by dilution of the bleach solution by water carried into the tank by the wet film. The accumulation of ferrocyanide ions slows the rate of bleaching to a much greater extent than would be predicted from the depletion of ferricyanide. In practice, a concentration of potassium ferrocyanide greater than 5 gm. per litre should be avoided. These concentrations can be detected using either the potentiometer method described by Brunner, Means, and Zappert² or, if desired, the colorimetric method described by Varden and Seary.⁷

The ferrocyanide can then be reoxidized to ferricyanide by the direct addition of liquid bromine to the solution. This reaction produces bromide ions equivalent to the number of re-oxidized ferricyanide ions and thus effectively regenerates the bleach bath. The chemical reactions of bleach exhaustion and rejuvenation are shown in Table 6.

TABLE 6

Bleach Exhaustion.

I. $4\text{Ag} + 4\text{K}_3\text{Fe}(\text{CN})_6 \longrightarrow \text{Ag}_4\text{Fe}(\text{CN})_6 + 3\text{K}_4\text{Fe}(\text{CN})_6$
II. $\text{Ag}_4\text{Fe}(\text{CN})_6 + 4\text{KBr} \longrightarrow \text{K}_4\text{Fe}(\text{CN})_6 + 4\text{AgBr}$

Bleach Rejuvenation.

$4\text{K}_4\text{Fe}(\text{CN})_6 + 4\text{Br}^- \longrightarrow 4\text{K}_3\text{Fe}(\text{CN})_6 + 4\text{KBr}$
--

It is recommended that a bleach bath be rejuvenated at intervals corresponding to 25 ft. of 35 mm. per litre of tank solution. This is conveniently done by providing two hard-rubber or ceramic mixing tanks for the bleach with pumps so that the solution may be pumped from the machine tank to either mixing tank for the rejuvenation treatment while machine operation is continued using the other tank of bleach solution.

A bleach exhaustion of 25 ft. per litre normally corresponds to a potassium-ferrocyanide concentration of 4.5 to 5.0 gm. per litre. With most technical grades of bromine, roughly 1.05 gm. or 0.33 cu. cm. per litre would be required to rejuvenate the bleach completely. In practice, however, in order to avoid the danger of adding an excess of bromine which would give excessive fuming and would be dangerously active both on the color film and on the tanks, spool banks, and so forth, it is desirable to retain a small amount of ferrocyanide in the bleach, normally 1.0 gm. per litre or equivalent to the exhaustion produced by 5 ft. of film per litre.

The addition of bromine should be made in a well-ventilated room or with a hood over the tank. Protective clothing and goggles should be worn, as contact with the bromine will cause bad burns. The addition should be made slowly with vigorous stirring continued for a minimum of 30 minutes after the bromine addition is complete. The bromine will be assimilated more rapidly and with less fuming if it is first dissolved in 5 to 10 times its own volume of cold methanol and the mixture then added to the bleach mixing tank.

A second potentiometer titration should be made after the bromine addition to check the accuracy of the replenishment.

3. Replenishment of Diluted Bleach

The dilution of the bleach by the wet film can be corrected by making additions of the original chemicals in the same proportion as they were originally compounded. The degree of dilution can be detected by specific-gravity measurements using a hydrometer. No chemical additions are necessary unless the dilution exceeds 10%. The specific gravity of fresh bleach No. 713 is approximately 1.110 at 20°C. Upon dilution, the specific gravity is reduced. An estimate of the degree can be made from the following calculation:

$$\frac{\text{Specific Gravity of Fresh Bleach Minus} \\ \text{Specific Gravity of Diluted Bleach} \times 100}{\text{Specific Gravity of Fresh Bleach Minus} \\ 1.000 \text{ (Specific Gravity of Water)}} = \frac{\text{Per Cent. Loss of Dry} \\ \text{Salts of Original Bleach.}}$$

Table 7 may be used as a guide for determining the required amounts of solid chemicals.

TABLE 7

<i>Bleach, Specific Gravity.</i>			<i>Film Bleach No. 713.</i>
Original Specific Gravity	..	..	1.110
At 5% Dilution	..	..	1.104
At 10% Dilution	..	..	1.098
At 15% Dilution	..	..	1.093
At 20% Dilution	..	..	1.087
At 25% Dilution	..	..	1.081
At 30% Dilution	..	..	1.076

TABLE 8.—TESTING OF CHEMICAL RAW MATERIALS
All new chemicals to be compared with types of known purity

<i>Chemical.</i>	<i>Testing Recommended.</i>	<i>Suggested Tolerance.</i>	<i>Recommended Action to Correct Deviation.</i>
Metol Hydroquinone Sodium Thiocyanate	Photographic test in No. 502 developer	$\pm \frac{1}{16}$ stop speed $\pm \frac{1}{16}$ stop color balance	If deviation can be corrected by small change in concentration, chemical can be used. Otherwise, return to manufacturer.
Color Developing Agent Sodium Bisulphite	Photographic test in No. 605 developer	$\pm \frac{1}{16}$ stop speed $\pm \frac{1}{16}$ stop color balance	If deviation can be corrected by small change in concentration, chemical can be used. Otherwise, return to manufacturer.
Sodium Sulphite Sodium Carbonate Potassium Bromide Potassium Iodide	When obtained from new supplier make photographic test in No. 502 developer	$\pm \frac{1}{16}$ stop speed $\pm \frac{1}{16}$ stop color balance	If deviation can be corrected by small change in concentration, chemical can be used. Otherwise, return to manufacturer.
Dipotassium Mono Sodium Ferricyanide or Potassium Ferricyanide Dibasic Sodium Phosphate Sodium Bisulphate	Potentiometric titration	Contains maximum of 1% Potassium Ferrocyanide $\pm 10\%$ concentration	Oxidize with bromine or return to manufacturer.
Acetic Acid Sodium Acetate	Titrate Dibasic Sodium Phosphate with type Bisulphate and vice versa Titrate Acetic Acid with Sodium Acetate and vice versa <i>pH</i>	$\pm 10\%$ concentration <i>pH</i> of 3% solution 3.0 to 4.0	Adjust relative quantities to obtain bleach <i>pH</i> of 5.7-6.0, maintaining a minimum phosphate concentration of 35 gm. per litre. Adjust relative quantities to obtain short stops of proper <i>pH</i> .
Potassium Chrome Alum			If <i>pH</i> deviation small, adjust with sodium hydroxide or sulphuric acid. If large, return to manufacturer.
Sodium Thiosulphate	When obtained from new supplier make photographic tests in No. 800 fixer	$\pm \frac{1}{16}$ stop speed $\pm \frac{1}{16}$ stop color balance	Return to manufacturer.

TABLE 9.—TESTING OF PROCESSING SOLUTION MIXES

<i>Chemical.</i>	<i>Testing Recommended.</i>	<i>Suggested Tolerance.</i>	<i>Recommended Action to Correct Deviation.</i>
No. 502 First	1. pH 2. Photographic Test 3. Analysis (if indicated by Photo Test)	1. 10-00-10-05 2. $\pm \frac{1}{4}$ stop speed $\pm \frac{1}{4}$ stop color balance 3. Correct chemical concentration until photographic test is satisfactory. Generally $\pm 5\%$ chemical concentration can be tolerated	Analyze for suspected ingredients, adjust concentration and make new photo test. Discard if error cannot be corrected.
No. 502 R-3 First Developer Replenisher	1. pH 2. Photographic Test 3. Analysis (if indicated by Photo Test)	1. 10-00-10-10 2. Same as for First Developer 3. Same as for First Developer	Analyze for suspected ingredients, adjust concentration and make new photo test. Discard if error cannot be corrected.
No. 605 Color Developer	1. pH 2. Photographic Test 3. Analysis (if indicated by Photo Test)	1. 10-30-10-40 2. Same as for First Developer 3. Same as for First Developer	Analyze for suspected ingredients, adjust concentration and make new photo test. Discard if error cannot be corrected.
No. 605 R-2 Color Developer Replenisher	1. pH 2. Photographic Test 3. Analysis (if indicated by Photo Test)	1. 10-35-10-45 2. Same as for First Developer 3. Same as for Color Developer	Analyze for suspected ingredients, adjust concentration and make new photo test. Discard if error cannot be corrected.
No. 859 Short Stop	1. pH	1. 5-2-5-3	Titrate with NaOH to determine total acidity and adjust concentration of acetic acid and sodium acetate on that basis.
No. 858 Short Stop (Replenisher for No. 859)	1. pH	1. 4-7-4-8	Titrate with NaOH to determine total acidity and adjust concentration of acetic acid and sodium acetate on that basis.
No. 901 Hardener	1. pH	1. 3-0-4-0	Discard if pH is below 2-5. Otherwise, adjust pH with sodium hydroxide or sulphuric acid if necessary to bring pH to between 3-0 and 4-0.
No. 713 Bleach	1. pH 2. Potentiometric titration	1. 5-7-6-0 2. Less than 1-0 gm. per litre potassium ferricyanide	Correct pH by adjusting dilbasic sodium phosphate or sodium bisulphate concentration. If ferrocyanide present, oxidize with bromine.
No. 800 Fixer	1. pH	1. 7-0-8-5	If pH is low, adjust with borax. If high, discard.

TABLE 10.—TESTING REQUIRED DURING MACHINE OPERATION

<i>Tank Solution.</i>	<i>Testing Recommended.</i>	<i>Interval to be Regularly Tested.</i>	<i>Suggested Tolerances.</i>	<i>Recommended Action to Correct Deviation.</i>
No. 502 First Developer	1. Temperature 2. pH 3. Bromide Analysis 4. Complete Analysis	1. 1 hr. 2. 1 hr. 3. 4 hr. 4. 48 hr. (or more often if difficulty is encountered)	1. $\pm 1^{\circ}\text{F}$. 2. 10.0-10.1 3. $2.0 \pm 0.1\text{gm}$. 4. $\pm 5\%$ variation in chemicals	1. — 2. Make immediate bromide analysis. 3. Make immediate complete analysis. Adjust replenishment rate. 4. Make photographic side test of tank solution. Adjust replenishment rate. Make additions of individual chemicals.
No. 859 Short Stop (after First and Color Developer)	1. Temperature 2. pH	1. 1 hr. 2. 1 hr.	1. $\pm 3^{\circ}\text{F}$. 2. 5.0-5.5	Adjust replenishment rate.
No. 901 Hardener (after First and Color Developer)	1. Temperature 2. pH	1. 1 hr. 2. 1 hr.	1. $\pm 3^{\circ}\text{F}$. 2. 3.5-4.5	Adjust replenishment rate.
No. 605 Color Developer	1. Temperature 2. pH 3. Bromide Analysis 4. Complete	1. 1 hr. 2. 1 hr. 3. 4 hr. 4. 48 hr.	1. $\pm 1^{\circ}\text{F}$. 2. 10.30-10.45 3. $1.0 \pm 0.05\text{ gm}$. 4. $\pm 5\%$ variation in chemicals	1. — 2. Make immediate bromide analysis. 3. Make immediate complete analysis. Adjust replenishment rate. 4. Make photographic side tests of tank solution, adjust replenishment rates. Make additions of individual chemicals.

TABLE 10 (continued)

Tank Solution.	Testing Recommended.	Interval to be Regularly Tested.	Suggested Tolerances.	Recommended Action to Correct Deviation.
No. 713 Bleach	1. Temperature 2. pH	1. 1 hr. 2. 1 hr.	1. $\pm 3^\circ\text{F}$. 2. 5.7-6.0 (does not usually change)	Change bleach solution. Pump machine solution to mixing tank where it can be rejuvenated with bromine and adjusted for salt concentration.
	3. Observe rate of Bleaching	3. 1 hr.	3. Bleaching of anti-halo silver should not require more than $\frac{1}{2}$ of total bleach times	
	4. Specific Gravity 5. Potentiometer Analysis	4. 8 hr. 5. 8 hr.	4. 1.000-1.120 5. Less than 5 gm. per litre of potassium ferrocyanide	
	1. Temperature 2. pH	1. 1 hr. 2. 1 hr.	1. $\pm 3^\circ\text{F}$. 2. 7.0-8.5 (does not usually change)	
	3. Observe rate of Fixing	3. 1 hr.	3. Clearing should not require more than $\frac{1}{2}$ of total fixing time	
No. 800 Fixer	4. Silver Analysis	4. 8 hr.	4. Less than 3 gm./litre silver	Change fixer tank. Recover silver by sulphide method.
	Sensitometric Control	15 min.	$\pm \frac{1}{4}$ stop speed $\pm \frac{1}{8}$ stop color balance	
Complete Machine Process				Correlate with bromide analysis, pH, and temperature differences and adjust replenishment rates as necessary. In severe cases make direct chemical additions based on chemical analysis.

4. Fixing-Bath Control

No replenishment or rejuvenation is recommended for the No. 800 fixer. Electrolytic methods of silver recovery are difficult to apply to neutral or alkaline fixing baths. It is recommended that the No. 800 fixer be used until a silver concentration of about 2.5 gm. per litre is reached or the time of clearing exceeds half the total available fixing time. When this point is reached, the fixer solution should be replaced by a fresh bath. The used solution may be treated with sulphides to recover the silver.

III. Summary of Testing Operations recommended for Control of Color-Processing Laboratory

A. Testing of Raw Materials

The recommended raw material tests are tabulated in Table 8. The frequency of tests will, of course, depend principally on the supply situation, size of shipments received, and number of manufacturers' lot numbers involved. Emphasis should be placed on pre-testing all lots of developing agents, sodium disulphite, and thiocyanate, since variations in these chemicals are most likely to affect results. Less attention is required with the other chemicals once the consistency of a new source of supply has been ascertained. It is advisable to keep careful records of stock, date each chemical received, and date of its use for ready reference in tracking down variations in a solution mix.

A thorough pre-testing policy will often prevent bad solution mixes and reduce the possibility of machine slowdown because of solution supply.

B. Testing of Solution Mixes

The recommended tests for solution mixes are shown in Table 9. Considerable attention should be paid to pretesting solution mixes before they are placed on the machine. Unless errors of solution mixing or of previously unobserved chemical differences are detected at this point, quality of machine output will suffer.

C. Testing During Machine Operation

The tests indicated in Table 10 should be made at consistent intervals to provide a constant flow of information to the machine control chemist.

In order to make correct decisions when photographic tests indicate trends away from normal, the control chemist should have at hand complete records of temperature and pH variations of all solutions as well as analysis of developers.

Acknowledgments

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APPENDIX 7

ANALYSIS OF DEVELOPERS AND BLEACH FOR ANSCO COLOR FILM*

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York*

Summary—Published procedures for black-and-white developer analysis are reviewed. New analytical methods are described or old ones modified to achieve the accuracy required for the complete control of all constituents of the developers used for Ansco color film. To evaluate the bleach solution prior to regeneration, a procedure is presented for the determination of ferrocyanide on in this solution.

Introduction

It has been recognized for some time that the accurate analysis of black-and-white developing solutions is especially important in the control of continuously replenished developers. As shown by Bates and Runyan,¹ it is of even greater importance in color-processing developers, because proper color balance must be maintained among three different emulsions. In the past few years, several articles have appeared in the technical literature concerning the analysis of black-and-white photographic developers, but nothing has been published on the analysis of developers used for processing color film because, until recently, color film was processed only by the manufacturer.

Little has appeared in the literature concerning the control of photographic bleach solutions, but when this solution is to be regenerated, as described by Bates and Runyan,¹ a method for its analysis is necessary.

The procedures here described are, for the most part, adaptations of methods previously reported for use with the usual black-and-white developers. They have been selected for their brevity, simplicity, and accuracy and have been used for the control of continuously replenished solutions for some time by unskilled technicians and require no special equipment other than a potentiometer.

Discussion

The procedures discussed here have been adapted especially for use with the Ansco developers listed in Table 1, but may be used for other developers with some modification.

TABLE 1

First Developer—A-502

Water, 65° to 90° Fahrenheit	..	..	750	millilitres
Metol	..	..	3	gm.
Sodium Sulphite	..	..	50	„
Hydroquinone	..	..	6	„
Sodium Carbonate Monohydrate	..	..	40	„
Sodium Thiocyanate	..	..	2	„
Potassium Bromide	..	..	2	„
Water to make	..	..	1	litre

* Presented May 18, 1948, at the SMPE Convention in Santa Monica.

Color Developer—A-605

Water, 65° to 70° Fahrenheit	.. ..	750 millilitres
Calgon .. ..	.. ..	1 gm.
Sodium Bisulphite .. ..	.. ..	2 "
Diethyl- <i>p</i> -phenylenediamine Hydrochloride	.. ..	4 "
Sodium Carbonate Monohydrate .. ..	.. ..	67.5 "
Potassium Bromide .. ..	.. ..	1 "
Water to make	1 litre

Determination of Metol and Hydroquinone

The first developer used in the Ansco color process is similar to the usual reversal first developer containing sodium thiocyanate.

All the earlier methods for the determination of metol and hydroquinone were based on two separate extractions of the developing agents and possessed several disadvantages, one of which was the determination of metol by difference. Baumbach² made a definite advance in 1946 by describing a single methyl acetate extraction method involving a potentiometric acid titration of metol followed by oxidation of both metol and hydroquinone with iodine. Shaner and Sparks³ modified this by using a U-tube extractor and methyl ethyl ketone as solvent. The difficulty in determining the end-point in the iodine titration is a disadvantage common to both methods. When the *pH* is maintained at 6.5 to 7.0, the solution is so highly colored by oxidation products that it is extremely difficult to see the blue starch-iodine end-point. Oxidation at low *pH* values results in a nearly colorless solution, but the iodine oxidation is not quantitative.

Because of the small sample used in the Shaner and Sparks procedure, the volume of acid needed to titrate the metol is very small. Four developers, cited by these authors, containing 2.0, 3.0, 0.22, and 0.31 gm. of metol per litre, require only 1.16, 1.74, 0.13, and 0.18 millilitres of 0.1 normal acid when determined in accordance with their procedure. Even if the procedure is changed and 0.05 normal acid is used, the volumes needed are still too small for reasonable accuracy with ordinary equipment. Moreover, with a sample of this size, the amount of metol present is too little to give a usable inflection in the titration curve.

The disadvantage of the iodine titration may be avoided by oxidizing the developers with ceric sulphate. Since this oxidation is performed in a strongly acid solution, highly colored oxidation products are not formed, and the end-point is easily observed. Stott⁴ described a ceric sulphate titration to determine developing agents, but he determined the end-point potentiometrically. Use of the ortho-phenanthroline ferrous complex (ferroin) as indicator makes the titration simpler and faster since the color change is easily discernible.

Equally satisfactory results have been obtained with methyl acetate, ethyl acetate, or isopropyl acetate as extracting solvent. With the methyl acetate used, a slight dark color appeared during the ceric sulphate titration which may be objectionable, but no such darkening occurred with the other two acetates. Methyl ethyl ketone, the solvent used by Shaner and Sparks, is itself oxidized by ceric sulphate, and therefore cannot be used.

This modified Baumbach procedure involving the acid titration of metol and ceric sulphate oxidation of both metol and hydroquinone has been tested on developer A-502 with variation in the concentration of the developing agents from 50% less to 20% more than normal. Within this range, the metol determination was found to be accurate to $100.7 \pm 2.4\%$ and the hydroquinone to $99.5 \pm 1.5\%$. Occasional values above 100% are probably due to mechanical carry-over of traces of developing solution with the solvent.

Determination of Diethyl-p-phenylenediamine Hydrochloride

Diethyl-p-phenylenediamine hydrochloride or its derivatives may be extracted in exactly the same manner as metol and hydroquinone. It may be titrated with acid the same as metol, but since it is more basic and no hydroquinone is present, a better inflection point is obtained in the titration curve. It may also be oxidized with ceric sulphate, and this oxidation using ferroin indicator is preferred to the potentiometric acid titration because it is faster and simpler. Immediately on addition of the ceric sulphate, a bright cherry red color is produced which is an intermediate oxidation product. The intensity of this color soon reaches a maximum, and then begins to fade until just before the end-point it disappears and is replaced by the same orange-pink indicator color observed in the metol-hydroquinone titration. Another few drops of reagent produce the usual indicator color change.

Determination of Sodium Sulphite and Bisulphite

The bisulphite used in developer A-605 is converted to sulphite by the sodium carbonate. The same analytical procedure for the sulphite ion is, therefore, applicable to both developers. Atkinson and Shaner³ and Stott⁴ have described a procedure in which an acidified standard iodine solution is titrated with the developer. This method may be used for these developers except that a weaker iodine solution should be used for developer A-605, since it contains a very small amount of sulphite ions. The only precaution required is that sufficient acid be present to keep the solution below pH 4 during the entire titration and thus prevent oxidation of the developing agents.

This method was found to be accurate to $100.4 \pm 2.0\%$ for concentrations ranging from 50% less to 25% more than the concentrations normally used.

Determination of Sodium Carbonate

Evans and Hanson⁶ described a procedure in which carbon dioxide and sulphur dioxide are liberated by acidification of the developer, the sulphur dioxide is then oxidized to sulphate and the remaining carbon dioxide is measured volumetrically. Atkinson and Shaner⁵ determined carbon dioxide by absorption in soda lime or Ascarite. A simpler method described by Stott⁴ involved the potentiometric titration of the developer with standard acid using glass or platinum and calomel electrodes. In this titration, the first inflection point in the titration curve corresponds to the change of carbonate to bicarbonate, but because of the buffering action of the sulphite present, this inflection is not at all sharp.

We have found it easier and faster to titrate the developer directly with standard acid to about pH 4 (grey color of methyl orange-indigo carmine), at which point the carbonate has been completely neutralized, and the sulphite has been converted to bisulphite. By deducting the volume of acid required for the sulphite present, the carbonate content may be calculated. Since developer A-605 has no alkalinity due to sulphite, no deduction is required. This method of determining carbonate was found to be accurate to $99 \pm 1\%$.

Determination of Potassium Bromide

Since developer A-502 contains thiocyanate which behaves very similarly to bromide, a separation of the two must be effected. To determine bromide in the presence of chloride or thiocyanate, Atkinson and Shaner⁵ recommended a rather lengthy iodometric procedure. To determine bromide in the presence of chloride, Stott⁴ used the method of Evans, Hanson, and Glasoe⁷ in which the developer was boiled, acidified, and boiled again, cooled, and titrated potentiometrically with silver

nitrate using silver and calomel electrodes. This method cannot be used in the presence of thiocyanate because the boiling removes some but not all of the thiocyanate.

Potassium bromide may be determined in developer A-502 in the range 1.0 to 3.5 gm. per litre with an accuracy of $100.0 \pm 0.2\%$ by oxidation with 30% hydrogen peroxide followed by the standard Volhard bromide procedure.

Developer A-605 does not contain thiocyanate, but does contain chloride ions from the colour-developing agent which is added in the form of its hydrochloride. The method of Evans, Hanson, and Glasoe⁷ cited above gives satisfactory results, but it has been found that boiling, either before or after acidification, is unnecessary. After acidification, the bromide may be determined by potentiometric titration with silver nitrate. Experience has shown that no advantage is gained by the addition of barium

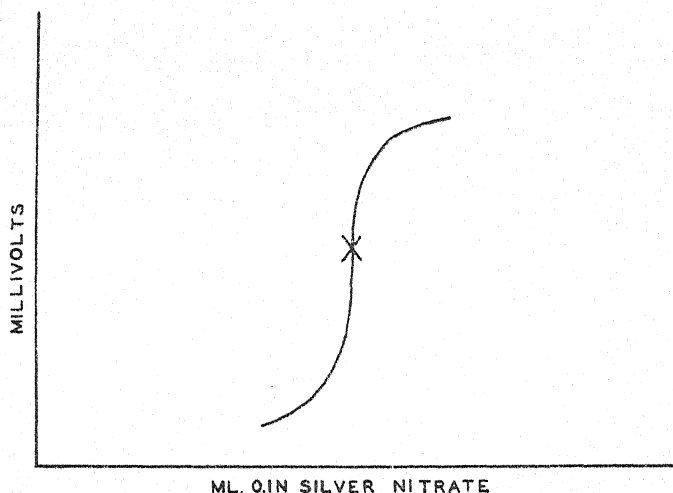


FIG. 1.—Titration curve for bromide plus thiocyanate.

nitrate, sodium acetate, or aluminum sulphate, as is sometimes recommended. The above procedure gave an accuracy of $100.0 \pm 0.5\%$ for concentrations of 1.0 to 3.5 gm. of potassium bromide per litre.

Determination of Sodium Thiocyanate

No method has been reported for the determination of thiocyanate in developers. Separation of thiocyanate from bromide is a lengthy procedure. Since the solubilities of silver thiocyanate and bromide are about the same, they are precipitated together and cannot be differentiated by the usual potentiometric titration. However, the sum of bromide and thiocyanate may be determined and, by deduction of the titre caused by the bromide, the thiocyanate concentration calculated. The Volhard method cannot be used because the developing agents present reduce the ferric ion added as indicator.

The sum of bromide and thiocyanate may be conveniently determined by acidification of the developer and direct potentiometric titration with standard silver nitrate to the inflection point using silver wire and calomel electrodes (Fig. 1). With this procedure the thiocyanate was determined with an accuracy of $100 \pm 1\%$.

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Determination of Ferrocyanide in Bleach

AnSCO color bleach A-713 has the following composition:

Dipotassium Mono Sodium Ferricyanide or Potassium Ferricyanide	..	100 gm.
Potassium Bromide	.. .. .	15 "
Dibasic Sodium Phosphate	.. .. .	40 "
Sodium Bisulphate	.. .. .	25 "
Water to make	.. .. .	1 litre

During use some of the ferricyanide is reduced to ferrocyanide. Varden and Seary⁸ described a colorimetric procedure for the rapid determination of color bleach exhaustion. When the bleach solution is to be regenerated with bromine as described by Bates and Runyan,¹ the concentration of ferrocyanide must be determined more accurately than is possible with the colorimetric method. Standard textbooks on chemical analysis describe the determination of ferrocyanide in acid solution by titration with potassium permanganate or ceric sulphate. Either of these oxidants

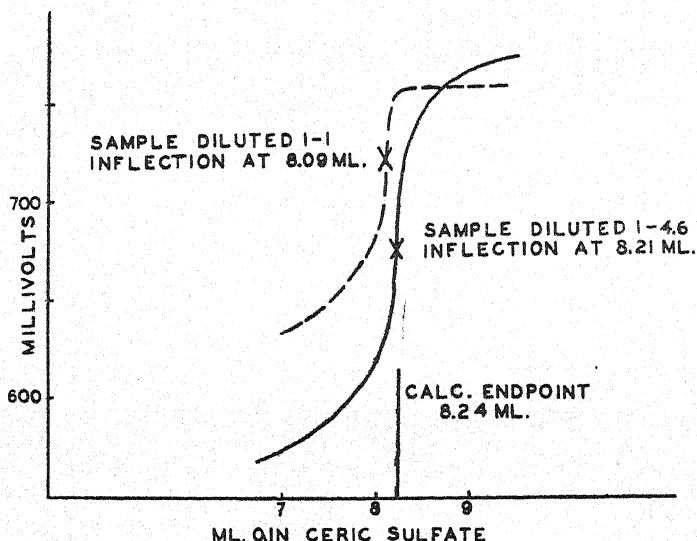


FIG. 2.—Effect of dilution on titration of ferrocyanide in bleach.

may be used with bleach A-713, but because of the deep color of the solution, the titration must be followed potentiometrically. In the permanganate titration, considerable time is required for the potential to reach equilibrium as the end-point is approached. With ceric sulphate equilibrium is reached more rapidly and the length of time required for the titration is thus shortened. It is necessary that the sample be diluted as described, since the position and magnitude of the inflection is influenced by the salt content of the solution (Fig. 2). The ceric sulphate method gave an accuracy of $99.5 \pm 0.5\%$ in the range of 2.5 to 10.0 gm. of ferrocyanide ion per litre.

Procedures

Determination of Metol and Hydroquinone

A. Metol—Pipette a 25.0-ml. sample of developer into 125-ml. separatory funnel. Add 2 drops of thymol blue indicator and one-to-one sulphuric acid until the color of the solution just turns yellow (pH 8 to 8.5). Add 12 gm. potassium bromide,

25 ml. of iso-propyl acetate, shake for 3 minutes and then allow the layers to separate completely. Drain the aqueous layer into a 50-ml. beaker, allowing a small amount of solvent to enter the stop-cock bore. Pour the solvent into a small dry beaker. Return the aqueous portion to the funnel, rinse the beaker with an additional 25 ml. of solvent and add this to the funnel. Repeat the shaking and separation.

Pour the first solvent extract, containing most of the extracted developing agents, from the first to a second and to a third small dry beaker, and finally to a 400-ml. beaker. After draining off the aqueous layer, pass the second portion of solvent through the same three small beakers to the 400-ml. beaker.

Add 100 ml. of distilled water and 50 ml. of methanol to the combined solvent layers and titrate potentiometrically with approximately 0.05 normal hydrochloric acid, using glass and calomel electrodes and mechanical stirring. Plot the titration curve of pH versus millilitres of acid and determine the inflection point.

Grams of metol per litre=

$$6.88 \times \text{millilitres of hydrochloric acid} \times \text{normality of hydrochloric acid.}$$

B. Hydroquinone—After the acid titration add 5 ml. of one-to-one sulphuric acid and 2 drops of 0.025 molar ferroic indicator (*o*-phenanthroline ferrous complex). Titrate with approximately 0.1 normal ceric sulphate solution, using mechanical stirring, until the pink-orange color changes to greenish yellow and remains changed for 30 seconds.

Grams of hydroquinone per litre=

$$2.20 \left[\text{millilitres Ce(SO}_4)_2 \times \text{normality Ce(SO}_4)_2 - \frac{\text{grams metol per litre}}{3.44} \right].$$

Determination of Diethyl-p-phenylenediamine Chloride

A 25.0-ml. sample of developer is extracted exactly as described in the procedure for metol. After the addition of 100 ml. of distilled water, 50 ml. of methanol, 5 ml. of one-to-one sulphuric acid, and 2 drops of 0.025 molar ferroin indicator to the combined solvent layers, the solution is titrated with approximately 0.1 normal ceric sulphate solution as described above.

Grams of diethyl-p-phenylenediamine hydrochloride=

$$4.01 \times \text{millilitres Ce(SO}_4)_2 \times \text{normality Ce(SO}_4)_2$$

Determination of Sodium Sulphite in Developer A-502

Place a portion of the developer in a 25-ml. buret. Pipette 20.0 ml. of approximately 0.5 normal iodine solution into a 250-ml. Erlenmeyer flask containing 100 ml. of distilled water and 5 ml. of concentrated hydrochloric acid. Titrate the iodine solution with the developer until the iodine color is nearly discharged. Add 3 ml. of starch solution and continue the titration until the solution becomes colorless.

Grams of sodium sulphite per litre=

$$\frac{\text{millilitres of iodine} \times \text{normality of iodine} \times 63}{\text{millilitres developer required}}$$

Determination of Sodium Bisulphite in Developer A-605

Place a portion of the developer in a 25-ml. buret. Pipette 5.0 ml. of approximately 0.1 normal iodine solution into 250-ml. Erlenmeyer flask containing 100 ml. of distilled water and 5 ml. of concentrated hydrochloric acid. Titrate the iodine solu-

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tion with the developer until the iodine color is nearly discharged. Add 3 ml. of starch solution and continue the titration until the solution becomes colorless.

Grams of sodium bisulphite per litre=

$$\frac{\text{millilitres of iodine} \times \text{normality of iodine} \times 52}{\text{millilitres developer required}}$$

Determination of Sodium Carbonate

Pipette a 20.0-ml. sample of developer into a 250-ml. Erlenmeyer flask containing 100 ml. of distilled water and 4 drops of methyl orange-indigo carmine indicator.* Titrate with approximately 1 normal hydrochloric acid to the grey end-point.

Grams of sodium carbonate monohydrate per litre A-502=

$$\frac{\text{millilitres HCl} \times \text{normality HCl} - (0.159 \times \text{grams Na}_2\text{SO}_3 \text{ per litre})}{0.323}$$

Grams of sodium carbonate monohydrate per litre A-605=

$$\frac{\text{millilitres HCl} \times \text{normality HCl}}{0.323}$$

Determination of Potassium Bromide in Developer A-502

Pipette a 25.0-ml. sample of developer into a 500-ml. Erlenmeyer flask. Add 10 ml. of 30% hydrogen peroxide and warm gently until a vigorous reaction begins and then remove the source of heat. When the reaction has subsided, heat to boiling and boil for 3 minutes. Cool, add 100 ml. of distilled water, and neutralize to alkacid paper by dropwise addition of one-to-one nitric acid and then add 5 ml. in excess.

Add 10.0 ml. of approximately 0.1 normal silver nitrate from a pipette followed by 3 ml. of saturated ferric ammonium sulphate solution which has been slightly acidified with nitric acid. (If desired 10 ml. of chloroform may be added and the solution well shaken to coagulate the precipitate.) Titrate with approximately 0.05 normal ammonium thiocyanate to the appearance of a dirty pink color which persists for 30 seconds.

Grams of potassium bromide per litre=

$$4.76[(10 \times \text{normality AgNO}_3) - (\text{millilitres NH}_4\text{SCN} \times \text{normality NH}_4\text{SCN})]$$

Determination of Potassium Bromide in Developer A-605

Pipette a 50.0-ml. sample of developer into a 400-ml. beaker and neutralize to alkacid paper by the careful addition of one-to-one nitric acid, and then add about 5 ml. in excess. Titrate potentiometrically with approximately 0.1 normal silver nitrate using silver and calomel electrodes. The end-point is the inflection in the curve of millivolts versus millilitres.

Grams of potassium bromide per litre=

$$2.38 \times \text{millilitres AgNO}_3 \times \text{normality AgNO}_3$$

Determination of Sodium Thiocyanate in Developer A-502

Pipette a 25.0-ml. sample of developer into a 400-ml. beaker containing 100 ml. of distilled water. Add one-to-one sulphuric acid until the solution has a pH of about

* The mixed indicator is prepared by dissolving 0.1 gm. methyl orange and 0.25 gm. indigo carmine in 100 millilitres of water. The end point is taken as the neutral grey color which occurs between the alkaline green and the acid violet shades. Bromphenol blue may be used in place of the mixed indicator, but the dichroic red-yellow end point is more difficult to see.

2 and titrate potentiometrically with approximately 0.1 normal silver nitrate using silver and calomel electrodes. The end-point is the inflection in the curve of millivolts versus millilitres.

Grams of sodium thiocyanate per litre=

$$3.24 \left[\text{millilitres AgNO}_3 \times \text{normality AgNO}_3 - \frac{\text{grams KBr per litre}}{4.76} \right].$$

Determination of Ferrocyanide in Bleach A-713

Pipette 50.0-ml. of bleach solution into a 400-ml. beaker, add 20 ml. of concentrated hydrochloric acid and dilute to about 300 ml. with distilled water. Titrate potentiometrically with approximately 0.1 normal ceric sulphate using platinum and calomel electrodes. Take the end-point as the inflection in the curve of millivolts versus millilitres or, in routine determinations, titrate to that millivolt reading which corresponds to the inflection point.

Grams of ferrocyanide ion per litre=

$$4.24 \times \text{millilitres Ce(SO}_4)_2 \times \text{normality Ce(SO}_4)_2$$

Acknowledgment

We wish to express our thanks to R. C. Johnston and C. A. Alfieri who assisted with the experimental work and to J. E. Bates and I. V. Runyan for their valuable suggestions.

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APPENDIX 8

METALLIC-SALT TRACK ON ANSCO 16-MM. COLOR FILM.*

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Summary—In 16-mm. AnSCO color motion picture film the silver is removed from the image, leaving dye in the three layers. The combination (maximum density) of the subtractive colors has a visual density of about 3, which is sufficient to produce good screen contrast. The maximum density, while being visually opaque, has a transmission band in the near infra-red in the region of 8,000 Angström units, which is the most sensitive region of the cesium-type phototube. While for many purposes this may not be objectionable, it can be overcome by differentially processing the film so that the sound-track modulations are opaque to red light without affecting the dye picture area. This paper describes a method by which differential treatment of the sound-track area can be accomplished.

THE method of processing AnSCO color film has been presented in numerous publications and the procedure for machine processing of 16-mm. AnSCO color film has been presented.¹ In this process, the silver is removed from the image area, leaving dye in the three layers. The combination (maximum density) of the subtractive colors—cyan, magenta, and yellow—has a visual density of from 2.8 to 3, which is sufficient to produce good screen contrast. The maximum density, while being visually opaque, transmits the far-red and near-infra-red radiation.

A sound track on AnSCO color film, processed in the usual way, is a dye track, the density of which is made up of the cyan, magenta, and yellow from the three layers. These dyes (Fig. 1) have good absorption in the visible region of the spectrum, but transmit the far-red and infra-red. If a track of this kind is played on sound-reproducing equipment utilizing a blue-sensitive phototube such as that described by Glover and Moore² (Fig. 2), the resulting volume will compare favourably with a silver track played on conventional equipment (Fig. 3).

Most sound-projection equipment, however, uses a cesium-type phototube (Fig. 4). This applies particularly to 16-mm. projectors. This tube has most of its sensitivity in the near infra-red region of the spectrum. The dye track, therefore, is not so efficient as a metallic type of track for modulating a light beam from an incandescent source when read by a cesium-type phototube.

The easiest and most direct approach to the solution of this problem is to suggest the use of a blue-sensitive phototube.³⁻⁶ Since it seems unlikely that a change-over to blue-sensitive phototubes will be made for some time, differential processing of the picture and sound track is necessary to make the sound-track modulations opaque to infra-red light. Differential treatment of the sound-track area of motion picture film is not new to the motion picture industry. The patent literature⁷ describes many procedures and methods for such treatments, each one more or less special and adapted to the process being used. All such processes involve special equipment and techniques which add extra steps to the processing procedure. Furthermore, because the sound track must be confined to a definite area of the film specifically defined by established standards,⁸ precision application equipment is required and skilled technicians must be available to operate it.

Patent literature⁹ teaches that, in the case of Kodachrome, the sound-track area may be treated with a solution of a sulphide plus an iodide in order to retain the metallic salts in the sound-track area and thus increase its opacity to infra-red light.

* Presented October 28, 1948, at the SMPE Convention in Washington.

A procedure for increasing the opacity of 16-mm. Ansco color duplicating film to infra-red light has been worked out in which the silver halides forming the modulations are converted to silver sulphide. This treatment produces a sound track on Ansco color film which compares favourably in volume with a silver track when reproduced on the conventional red-sensitive phototube (Fig. 3). Careful measurements have not shown any serious distortions introduced in the track by this treat-

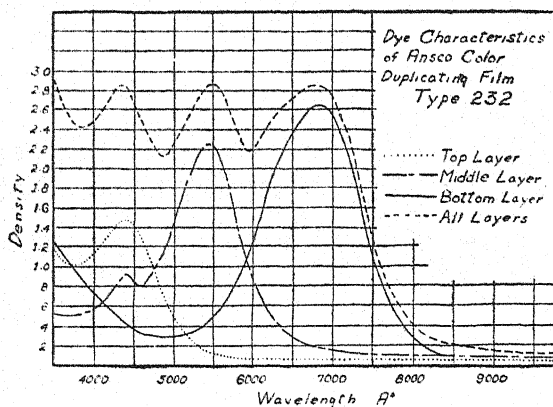


FIG. 1.

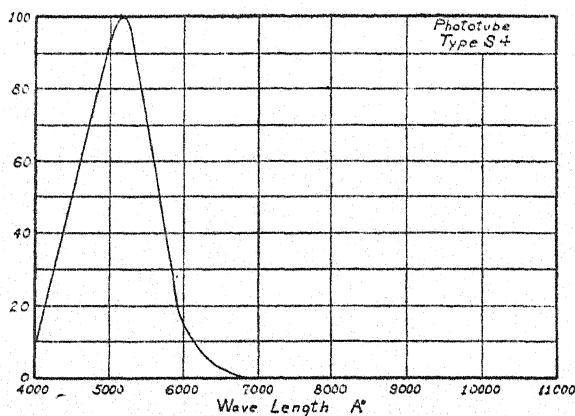


FIG. 2.

ment. Listening-test comparisons between a treated track and a silver track on a large number of samples indicated that there is a slight increase in noise level over the silver track, but in no case was this found sufficient to be judged objectionable.

Unfortunately, the filter layer used in Ansco color film was found to contribute a slight stain to the clear area. The maximum absorption band of this stain, however, does not correspond to the peak of sensitivity of the cesium photo surface; therefore it is not so objectionable as a visual inspection of the track might indicate.

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For reversible-type 16-mm. film, the variable-area sound track is preferable and with a track treatment of this kind on reversible color film, the characteristics of the treated track lend it best to the variable-area method.

For economical reasons, the procedure and equipment used for treating the film have been worked out to operate in connection with the Ansco color-film processing

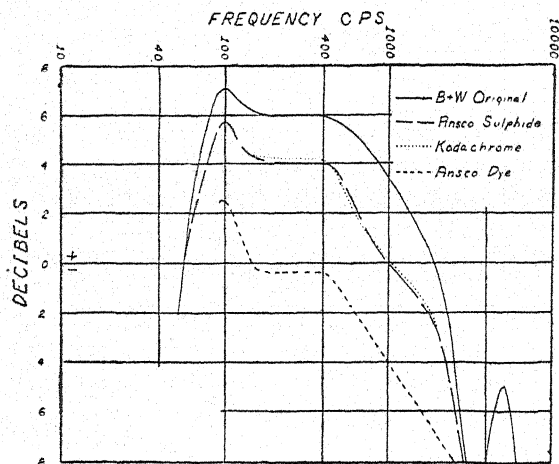


FIG. 3.

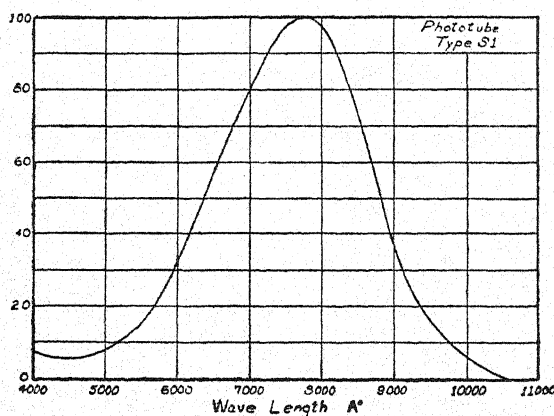


FIG. 4.

machines operating at the normal processing speed. The equipment can be used with any type of developing machine providing a uniform steady film flow. A uniform flow of film through the equipment is absolutely essential for satisfactory results.

In practice, since it is a reversal process, the sound track on Ansco color duplicating film is exposed from a positive-type track. A recorded track having charac-

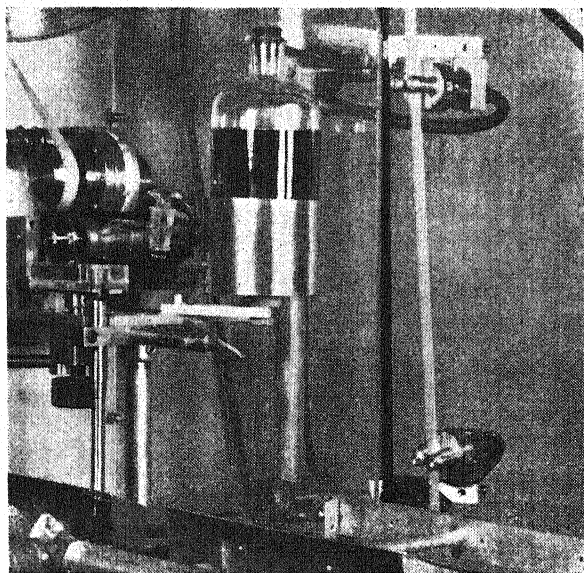


FIG. 5.

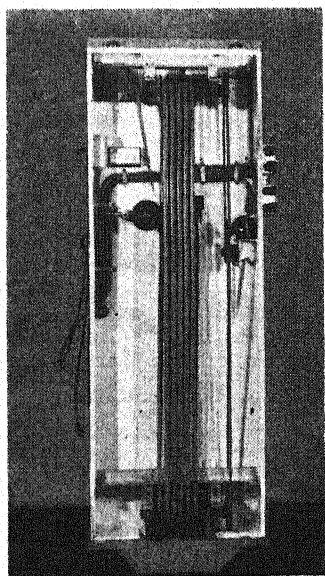


FIG. 6.

COLOUR CINEMATOGRAPHY

teristics favourable for printing on black-and-white reversible duplicating stock will be suitable for printing on Ansco color duplicating film. After printing, the color film is processed in the usual way up to the wash before the color developer. In the middle of this wash, the film is led out of the wash into the sound-track-treating equipment (Table 1). In the sound-track-treating equipment, the film is first surface-dried to prevent creeping of the treating solution beyond the area allocated for the sound track. This drying is accomplished by passing the film through air squeegees (Fig. 5) and then into a small drying cabinet (Fig. 6). This drying requires about 50 seconds. From the drying chamber, the film is led over the applicator roller and here the edge-treating solution is applied to the track area (Fig. 7). The reaction of the solution is very rapid; only about 15 seconds are required to convert the silver

TABLE 1.—ANSKO COLOR REVERSIBLE 16-MM. SOUND-FILM PROCESS

Dark	1. First Develop ..	8-14 minutes
	2. Rinse	5-10 seconds
	3. Stop	3 minutes
	4. Hardener ..	3 "
	5. Wash and Second	
	Expose	Approximately 2 minutes
Sound-Track Treatment—→		
	A. Feed to Edge-Treating Device	
	B. Air Squeegee and Surface Dry—	45-55 seconds
	C. Edge-Treating Solution Application	
	D. Reaction Time—	15 seconds
	E. Jet Wash (Track Downward)—	5 seconds
	F. Return to Color Processing Machine	
←		
White Light	6. Finish Wash ..	Approximately 1 minute
	7. Color Develop..	10-15 minutes
	8. Rinse	5-10 seconds
	9. Stop	3 minutes
	10. Hardener ..	3 "
	11. Wash	3 "
	12. Bleach	6 "
	13. Wash	3 "
	14. Fix	6 "
	15. Wash	9 "
	16. Dry	

halides in the track to silver sulphide. The treating solution is essentially an aqueous solution of sodium sulphide with Cellosize WS-100 (hydroxyethyl cellulose) added to increase the viscosity (Table 2). After this reaction, the excess solution is washed off the track area and the film is returned to the wash tank from which it was taken. This entire treatment requires about 75 seconds. After its return to the wash tank, the film continues on through the rest of the process in the usual way.

TABLE 2.—EDGE-TREATMENT SOLUTION FORMULA

Cellosize WS-100	100 cu. cm.
Sodium Sulphide (Anhydrous)	20 gm.
Water to make	1 litre

Although this process of treating the track requires care, it is a straightforward procedure and is not untidy or odorous. The solution contains sodium sulphide; however, the amount of solution required is small, only about 10 cu. cm. or a third

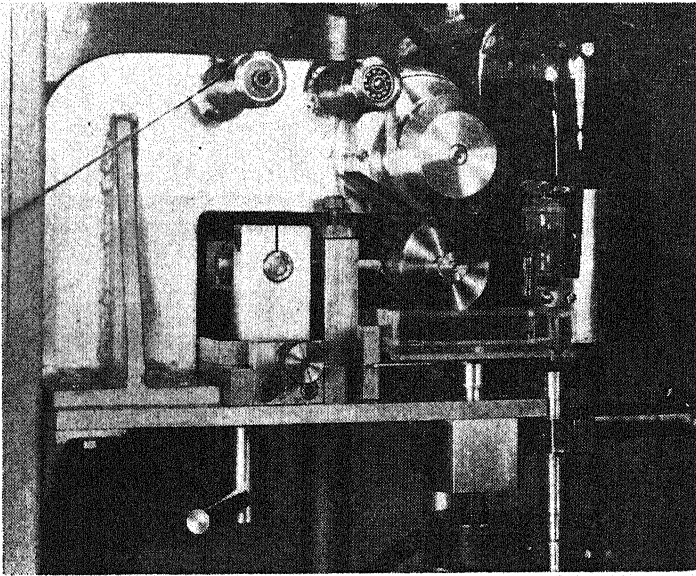


FIG. 7.

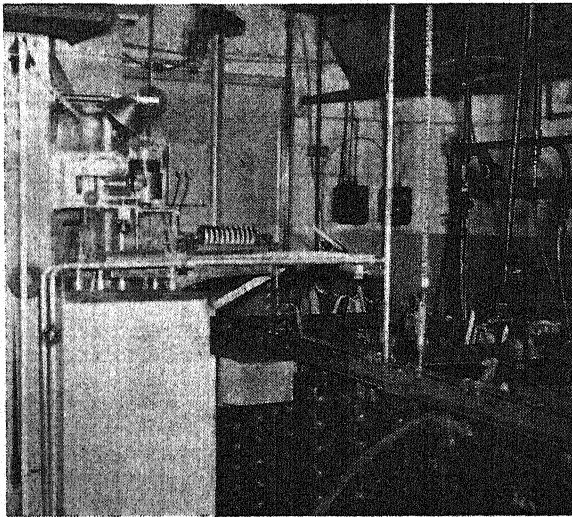


FIG. 8.

of an ounce is required for 100 feet of film. Therefore the handling of the solution presents no problem or hazards in the processing laboratory if ordinary precautions are taken.

The unit is compact and portable on casters (Fig. 8), and when used it is moved alongside the developing machine and remains there through the run. Even for developing machines continuously processing sound film, the portable construction is desirable. This type of construction makes it possible to move the unit out of the way to give free access to the processing machine for maintenance and cleaning.

The unit itself does not propel the film. This is accomplished entirely by the processing machine. Actually, the processing machine pulls the film through the sound-track-treating unit. In order that no undue strain be placed on the film, the sound-track-treating unit is tendency-driven, that is, the shafts in the rollers of the drying cabinet are turning in loose rollers. After leaving the drying cabinet, the film is fed

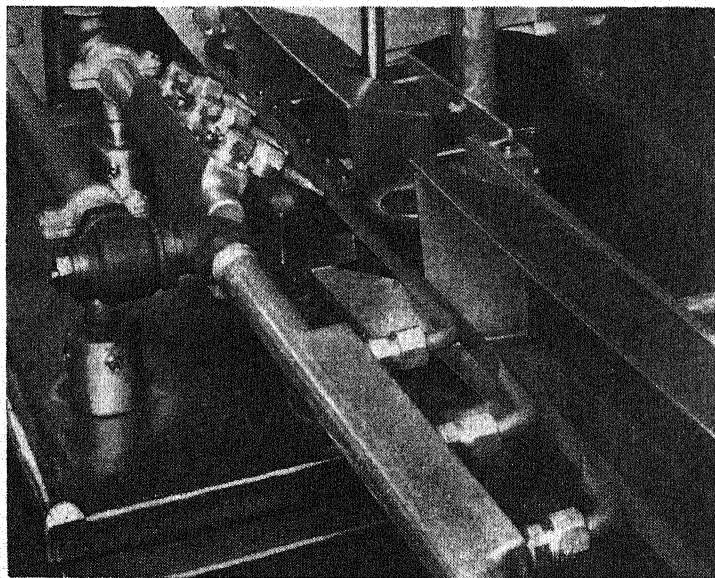


FIG. 9.

over a roller cluster to guide it accurately over the edge-treating roller (Fig. 7). Here, the sound-track area comes in contact with a bead of the edge-treating solution carried on the slightly concave periphery of the applicator wheel. The bead wheel travels at a slightly faster rate of speed than the film and in the same directions as the film. This maintains a uniform bead in contact with the track area.

The amount of solution applied is controlled by the depth of dip of the applicator wheel in the solution, and lateral movement of the wheel is controlled by two micrometer adjustments on the applicator assembly. With these adjustments, no difficulty has been experienced in confining the track area within the established standard. After edge-treating, the solution is allowed to react for 15 seconds and is then removed by a special spray washing the excess solution off the track area (Fig. 9). From this point, the film is returned to the processing machine and continues on through the rest of the process in the usual way.

Sound tracks processed in this way are permanent and are no more subject to scratches and abrasions than normal silver sound tracks made on black-and-white film. Any subsequent treatment, such as lacquering or waxing, which can be applied safely to the color film, will not harm the treated sound track.

References

- (1) FORREST, J. L., "Machine processing of 16-mm. Ansco color film," *J. Soc. Mot. Pict. Eng.*, 45 (November, 1945), pp. 313-327.
- (2) GLOVER, A. M., and MOORE, A. R., "A phototube for dye image sound track," *J. Soc. Mot. Pict. Eng.*, 46 (May, 1946), pp. 379-387.
- (3) GLOVER and JONES, "A new high sensitive photo-surface," *Electronics*, August, 1940.
- (4) DREW, R. O., and JOHNSON, S. W., "Preliminary sound track tests with variable-area dye tracks," *J. Soc. Mot. Pict. Eng.*, 46 (May, 1946), pp. 387-405.
- (5) GORISCH, R., and GORLICH, P., "Reproduction of color film sound records," *J. Soc. Mot. Pict. Eng.*, 43 (September, 1944), pp. 206-214.
- (6) SCHINZELL, *Kinotechnik*, p. 464, 1929.
- (7) U.S. Patents 2,143,787; 1,973,463; and 2,330,796.
- (8) ASA Standard Z52.16-1944 or succeeding Standard.
- (9) U.S. Patent 2,258,976.

APPENDIX 9

DU PONT COLOR FILM.

Du Pont Type 275 35-mm. Color Release Positive Film for Professional Use

Manufactured by E. I. Du Pont de Nemours and Company, Wilmington, Delaware, U.S.A.

THIS remarkable product is a multilayer film for release printing from three colour separation negatives. The film has three light sensitive layers, each sensitized differently so that the desired layer can be exposed by suitably filtered light.

The light sensitive silver halide grains in each layer are suspended in three synthetic polymer layers which combine the functions of carrier and colour generators. The polymer molecules have attached to them chemically the necessary colour-forming structure to produce the three subtractive primary colours, yellow, magenta and cyan.

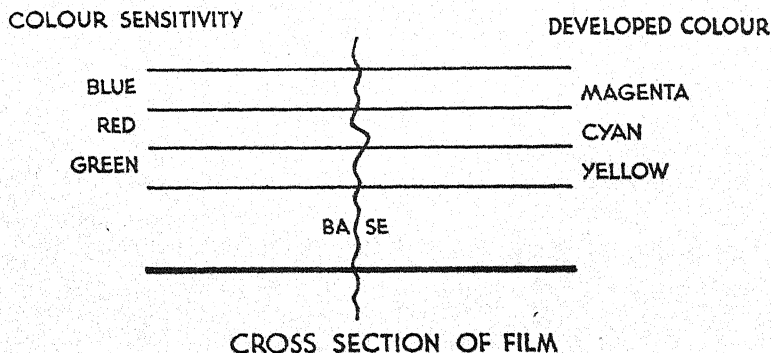


FIG. 1.

The silver grains, when developed, are intimately in contact with the colour-forming groups. This results in very high efficiency of dye formation and the use of very thin layers for increased resolution.

The important magenta layer is on top while the least important yellow layer is on the bottom. This contributes to sharpness of definition. (See cross-section above.)

Printing

Conventional types of registration printing equipment may be used. Colour filters are used in order to record the colour separation records in the appropriate layers of the multilayer positive. The sequence of printing is as follows:

<i>Colour Separation Record</i>	<i>Filter Used for Printing</i>
Red	Corning 2403
Green	Corning 5113 (half-thickness)
Blue	Du Pont Defender 60G

Printing can be carried out satisfactorily using a registering step-printer at 22 feet per minute, with illumination from a 500 W. clear projection-type tungsten filament lamp with a spherical reflector. The exposures in meter-candle-seconds required to produce a neutral image of a density of 3.0 are:

Blue exp. (magenta image)	440	Meter-candle-seconds
Red exp. (cyan image)	880	" " "
Green exp. (yellow image)	620	" " "

Processing

Du Pont Color Release Positive Film may be processed in conventional types of developing machines having suitable tank arrangement to permit the sequence of processing operations shown below. Processing consists of four chemical steps with suitable rinses and washes at appropriate points, based on 70° F. processing temperature.

1. Develop	10 minutes
2. Rinse	5-10 seconds
3. Fix	6 minutes
4. Wash	5 "
5. Bleach*	5 "
6. Wash	5 "
7. Fix	3 "
8. Wash	10 "

The times given above are to be considered approximate and will vary slightly for individual processing machines, depending upon conditions of agitation, etc.

The film carries an anti-halation backing which is removed automatically during processing.

Processing Solutions

Colour Developer

P-amino diethylaniline hydrochloride	5.2 lb.
Sodium sulphite	20.9 "
Sodium carbonate monohydrate	97.8 "
Potassium bromide	4.0 "
Water to	250.0 gall.

First Fixer

Hypo	167.2 lb.
Sodium sulphite	10.5 "
Borax	12.5 "
Acetic acid glacial	3,784.0 c.c.
Potassium alum	14.6 lb.
Water to	250.0 gall.

Bleach

Potassium ferricyanide	209.0 lb.
Boric acid	20.9 "
Borax	10.5 "
Water to	250.0 gall.

* If sulphiding of track is employed, this may occur after a 1-minute wash following Step No. 5. Processing then proceeds to Step No. 6.

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Second Fixer

Hypo	418.0 lb.
Water to	250.0 gall.

The above information has been included by courtesy of Du Pont de Nemours and Company, to whom the writer is gratefully indebted.

APPENDIX 10

GEVACOLOR

(Manufactured by Photo-Produits Gevaert, Antwerp, Belgium)

Much of the following data has been supplied by Gevaert Ltd., of London, by whose courtesy it is included.

Classification. Three-colour subtractive process. Integral tripack, the emulsion layers incorporating non-diffusing colour couplers. Colour negative-positive system.

Camera. Normal.

Projection. Normal.

Printing. Normal with suitable means for grading for colour.

Processing. Colour development with colour coupling compounds.

TYPES OF GEVACOLOR FILM

Width		Meter Reading.		
35-mm.	Negative. Daylight type. Nitrate Base.	8	12	Camera Record
35-mm.	Positive. Release. Nitrate Base.	—	—	Release Printing

General Description. The origins of this process are identical to Agfacolor (see pp. 355-6). Furthermore, it is reasonable to assume that the material is made substantially in accordance with the emulsion coating and sensitizing data in FIAT FINAL REPORT 943, published by the U.S. Department of Commerce (see pp. 378-9). Gevaert have patented a number of colour couplers, so that it may well be that all the couplers are not identical to the German ones.

Structure. The structure of both negative and positive films seems to be identical to Agfacolor (Fig. 191 and Table 57). The blue light-barrier between the top layer (blue recording) and the second layer (green recording) is colloidal silver, corresponding, no doubt, to the German colloidal silver emulsion Type 00814 (see FIAT 943).

Processing. The processing of Gevacolor is very similar to that of Agfacolor, as will be evident from a comparison of the respective time-tables and formulæ (see pp. 370-372).

Processing Formulae

Negative or Positive Colour Developer

Solution A

N-diethyl <i>p</i> -phenylenediamine sulphate	..	..	3.0 gm.
Water (distilled)	..	..	200.0 c.c.

COLOUR CINEMATOGRAPHY

DEVELOPMENT TIME-TABLE. GEVACOLOR NEGATIVE-POSITIVE

Treatment.	Negative.		Positive with silver track.			pH.
	Time (min.).	Total Time.	Time (min.).	Total Time.	Temp.	
Colour Development	7	7	10	10	65°F. $\pm 2^\circ$	10.8 ± 0.1
Spray Rinse					"	
Fixing Bath	8	15	8	18	"	
Spray Wash	15	30	15	33	59°F.—68°F.	
Colloidal Silver Bleach	omit	—	4	37	65°F. $\pm 2^\circ$	4.2 ± 0.8 —0.0
Rinse	omit	—	2	39	"	
Bleach Bath	8	38	omit	—	—	5.0 ± 1.0
Viscous Bleach ..	omit	—	4	43	—	
Stop Bath	omit	—	2	45	65°F. $\pm 2^\circ$	
Spray Wash	5	43	5	50	"	
Fixing	5	48	5	55	"	8.0 ± 1.0
Spray Wash	2	50	2	57	59°F.—68°F.	
Hardening Bath and Stabilizer	5	55	5	62	65°F. $\pm 2^\circ$	10.8 ± 0.2
Spray Wash	15	70	15	77	59°F.—68°F.	
Dry						

Solution B

Sodium Sulphite (cryst.)	4.0 gm.
Hydroxylamine HCL	1.2 "
Sodium Carbonate (anhyd.)	50.0 "
Potassium Bromide (for positive)	2.5 "
Potassium Bromide (for negative)	0.5 "
Water (distilled)	800.0 c.c.

Add Solution A to B at least 24 hours before use.

Regenerator Negative or Positive Colour Developer

Solution A

N-diethyl <i>p</i> -phenylenediamine sulphate	3.0 gm.
Water (distilled) to make	100.0 c.c.

Solution B

Sodium Sulphite (cryst.)	4.0 gm.
Hydroxylamine HCL	1.6 "
Sodium Carbonate	50.0 "
Water (distilled) to make	800.0 c.c.

Add Solution A to B at least 24 hours before use.

Use 50 litres per 1,000 metres of film processed.

Fixing Bath (1st)

Sodium Thiosulphate (hypo)	300.0 gm.
Sodium Bisulphite	12.0 "
Sodium Sulphite (anhyd.)	13.0 "
Acetic Acid (glacial)	10.0 c.c.
Potassium Alum	12.0 gm.
Add Water to make	1.0 litre

Bleaching Bath

Acetic Acid (glacial)	15.0 c.c.
Sodium Hydroxide	15.0 gm.
Potassium Ferricyanide	100.0 „
Potassium Bromide	10.0 „
Add Water to make	1.0 litre

The colloidal silver yellow filter layer is removed in this bleach.

Fixing Bath

Sodium Thiosulphate (hypo)	200.0 gm.
Sodium Sulphite (anhyd.)	10.0 „
Add Water to make	1.0 litre

Hardening Bath and Stabilizer

Formalin (40% stock solution)	12.5 c.c.
Sodium Carbonate (anhyd.)	10.0 gm.
Add Water to make	1.0 litre

Stabilizes the colours and prevents subsequent fading.

Renewal: 150 litres per 1,000 metres of film processed.

Bleach for Colloidal Silver Filter Layer
(for Positive with sound-track)

Acetic Acid (glacial)	3.0 c.c.
Sodium Hydroxide (caustic soda)	0.75 gm.
Potassium Ferricyanide	5.0 „
Add Water to make	1.0 litre

Renewal: 150 litres for 1,000 metres of film processed.

Viscous Bleach

(for Positive picture area, leaving sound-track free)

Carboxymethyl Cellulose	50.0 gm.
Potassium Ferricyanide	100.0 „
Nekal	5.0 „

Renewal: 150 litres for 1,000 metres of film processed.

Note.—50 gm. of the carboxymethyl cellulose are added through a strainer into 1,000 c.c. of water. After constant stirring for about one hour the paste thickens and dissolves completely. The potassium ferricyanide and Nekal are then dissolved in the solution.

Stop Bath for Viscous Bleach

Sodium Sulphite (anhyd.)	50.0 gm.
Water	1.0 litre

Renewal: 100 litres per 1,000 metres of film processed.

Printing. Printing machines must embody means for colour grading by the insertion of compensating filters. The continuous printers described on p. 300 would be suitable. Gevaert recommend the Debie "Matipo," which has a unique automatic colour filter band and light control (see p. 375). Light control by voltage regulation is unsatisfactory owing to change of colour temperature and its effect upon the spectral distribution of energy. Accordingly, light flux must be regulated by a

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diaphragm as in the "Matipo" band, or the insertion of neutral filters as in the Dufaycolor printing machine.

Gevaert compensating filters, Yellow (minus blue), Magenta (minus green) and Cyan (minus red) are supplied in a series of six graduated densities, designated 00—10—20—30—60—90.

Selection of the appropriate combination is made in two stages.

(a) Prints are made using the following tabulated combinations:

<i>No. of the aperture in the "Matipo" Band.</i>	<i>Yellow Y.</i>	<i>Magenta M.</i>	<i>Blue-Green (Cyan) C.</i>
4	00	00	00
4	30	00	00
4	60	00	00
4	90	00	00
6	00	30	00
6	30	30	00
6	60	30	00
6	90	30	00
7	00	00	30
7	30	00	30
7	60	00	30
7	90	00	30
7	00	60	00
7	30	60	00
7	60	60	00
7	90	60	00
9	90	90	00
9	30	90	00
9	60	90	00
9	90	90	00
10	00	00	60
10	30	00	60
10	60	00	60
10	90	00	60
13	00	00	90
13	30	00	90
13	60	00	90
13	90	00	90
9	00	30	30
10	00	60	30
12	00	90	30
12	00	30	60
13	00	30	60
15	00	90	60
15	00	30	90
16	00	60	90
18	00	90	90

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(b) A further test print is made using the best filter combination from test (a) as a pre-filter (or fixed screen) and then using the following accessory combinations:

<i>No. of the aperture in the "Matipo" Band.</i>	<i>Yellow Y.</i>	<i>Magenta M.</i>	<i>Blue-Green (Cyan) C.</i>
4	00	00	00
4	10	00	00
4	20	00	00
4	30	00	00
5	00	10	00
5	10	10	00
5	20	10	00
5	30	10	00
5	00	20	00
5	10	20	00
5	20	20	00
5	30	20	00
6	00	30	00
6	10	30	00
6	20	30	00
6	30	30	00
5	—	—	10
5	10	—	10
5	20	—	10
5	30	—	10
6	—	—	20
6	10	—	20
6	20	—	20
6	30	—	20
7	—	—	30
7	10	—	30
7	20	—	30
7	30	—	30
6	—	10	10
7	—	20	10
7	—	30	10
7	—	10	20
8	—	20	20
8	—	30	20
8	—	10	30
9	—	20	30
9	—	30	30

When judging the positive, the correction to be applied is to use a filter of the same hue as that which is predominant when viewed by the projection illuminant— and vice versa for the negative.

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<i>Dominant Colour.</i>	<i>Correction to be applied when viewing</i>	
	<i>Positive.</i>	<i>Negative.</i>
Cyan	Cyan	Magenta, Yellow
Magenta	Magenta	Cyan, Yellow
Yellow	Yellow	Cyan, Magenta
Blue	Cyan, Magenta	Yellow
Red	Yellow, Magenta	Cyan
Green	Cyan, Yellow	Magenta

The final combination for printing is determined by adding the "pre-filter" setting (see (a) above) to the best filters found for test (b).

Example I

The two following instances are given to demonstrate the above:—

(i) The filters used as pre-filters (fixed screens), for example, C30 and M60, are the same colour as those which give the best balance in the second trial: for example, C20 and M10.

The correct filter to use for the final print will, therefore, be composed of the filters C50 (C30 and C20) and M70 (M60 and M10).

(ii) If using filters C30 and M60 as a pre-filter, it is necessary, according to the results of the second trial, to add filters M10 and Y20, the final combination will then become:

$$\begin{aligned} &Y\ 20 \\ &M70(=M60-M10) \\ &C\ 30 \end{aligned}$$

It is as well to note here that the apertures in the Matipo band as shown in the above tables, must be increased in accordance with the higher density of the magenta or blue-green filters in use due to the grey content of these dyes.

For every 10 points increase in the blue-green filter, the aperture must be increased by one unit: for an increase of 20 points in the magenta filter, the aperture must be increased by one unit.

Assuming the dyes used in all the filters were ideal ones, a combination of one of each of the three colours of the same number will give a grey density corresponding to a difference in aperture of 1.5 units.

Bearing the above in mind, the aperture must be reduced by $1\frac{1}{2}$ units for every 10 numbers by which the three filters are simultaneously decreased.

Example II

In (ii) of Example I, Y20, M70 and C30 can be substituted by the combination M50 and C10, obtained by subtracting from the index of each filter the number 20, i.e., the smallest of the three indices.

This reduction in the density of the filter must be compensated by a corresponding reduction in the diameter of the aperture in the control band.

(1) First allow for a reduction in the density of the three filters, or in this particular instance, a decrease of

$$\frac{20}{10} \times 1.5 = 3 \text{ units}$$

(2) Then allow for the reduction in density of the magenta and blue-green filters,

or decrease in the magenta filter of $\frac{20}{20} \times 1 = 1$ unit.

Decrease in the blue-green filter of $\frac{20}{10} \times 1 = 2$ units.

In practice, a decrease of 20 units for all three filters must be compensated by a decrease of $2 \times 1.5 = 3 + 1 + 3 = 6$ units in the number of the aperture in the control band.

In order to correct for under or over exposure in the negative, apertures must be either decreased or increased. To facilitate this control, tests with various apertures *without* filters must be added to both test strips.

Sound Printing. Sound is printed in the usual manner. However, in order to avoid a drop in quality due to light diffusion through the thickness of the emulsions, a blue filter (No. B.488) must be inserted. In this way the sound track is only recorded in the top layer.

Events are proving correct the prediction made in the Historical Summary (pp. 26-7). Already we have Ansco Negative and Positive Color Film, Gevaert Negative and Positive Color Film, and a Ferrania (Italian) Negative and Positive Color Film promised shortly. All these materials are derivatives of Agfacolor. Agfacolor negative and positive is being made in Russia, and in Germany it is coming to life again at the I.G. plant at Leverkusen, where Agfa made bromide paper.

APPENDIX II

THE DUGROMACOLOR PROCESS

DUGROMACOLOR is an additive process developed in France by Roger Dumas, Georges Grosset, and André Marx. Special lenses, of which the details are not revealed, are used for taking and projecting, and are said to eliminate parallax. For taking, the lens and prism block, stated to be adaptable to any camera,

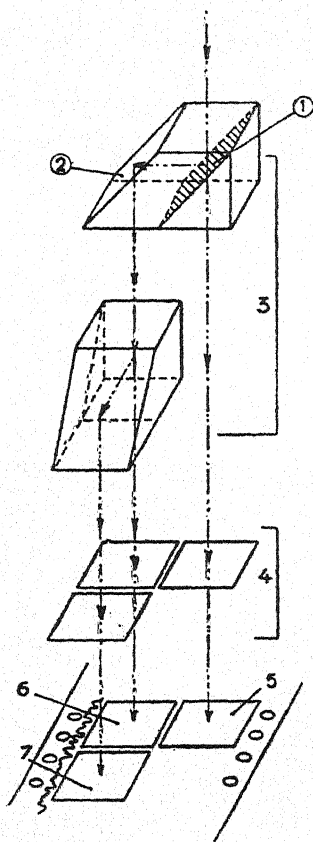


FIG. 1.

comprises a beam-splitting component providing three sub-standard images within the area of a single frame. Standard tricolour filters are employed. Lenses of 32-mm. focus or greater may be used. It is claimed that "the fact that the rays forming the three images are parallel to one another makes the use of a plano-convex field lens unnecessary." From the description it seems that the beam-splitter block is

placed between a single objective and the image plane. A multiple lens unit is employed to project the three images in superposition on the screen. The beam-splitter illustrated appears to necessitate unequal glass paths, and no means for equalizing these paths is indicated.

Reference

BLEMMEC, O., *Le Cineopse*, 25, 4, No. 274 (February, 1949).

APPENDIX 12

FURTHER PROCESSES RECENTLY ANNOUNCED

CHROMART

(Anglo-American Colour Photographic Industries, Ltd.,
30, Queen's Grove, St. John's Wood, London.)

Classification.—Two- or three-colour negative-positive multilayer process, the emulsion layers incorporating non-diffusing colour couplers.

Camera.—Normal.

Projection.—Normal.

Printing.—Normal, with suitable means for grading for colour.

Processing.—With minor modifications said to be similar to the processing of Agfacolor motion picture film.

General Description

This process is based upon the patents of Hans von Fraunhofer, a Hungarian subject residing in England. Two "processes" have been described. A two-colour version called the "Simplex" process, and three-colour negative-positive materials called the "Chromart Tricolor" process.

Structure

The two-colour process consists of a two-layer negative material of unorthodox design.

	<i>Sensitizing</i>	<i>Coupler Incorporated</i>	<i>Filter Layer</i>
Top	Ortho	Cyan	—
Filter Layer	—	—	Colloidal Silver
Bottom	Red Sensitized (No Green Sensi.)	Magenta	
		Film Base	

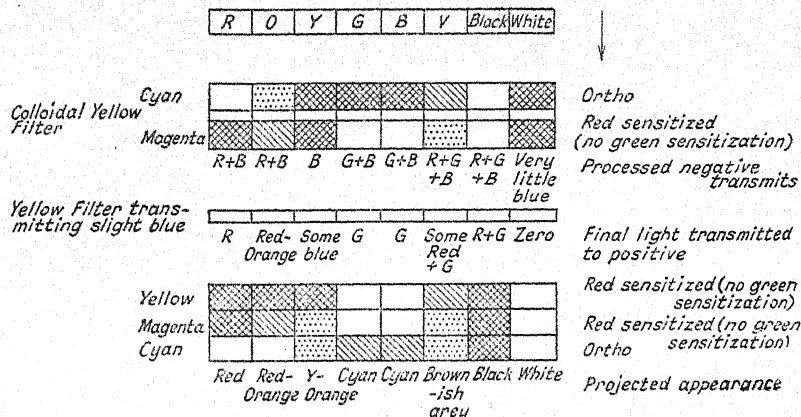
For the positive print a *three-layer* material is used of unorthodox structure. The top layer is red sensitized (no green sensitizing) and contains a yellow coupler, the middle layer is *also* red sensitized (no green sensitizing) and contains a magenta coupler. The bottom layer is green sensitized (ortho) and contains a cyan coupler. For control the printing light is filtered with a yellow (minus blue) filter which may be varied in density. Thus mainly red and green light emanates from the magenta and cyan layers of the original record with more or less active blue light transmitted depending upon the density of the yellow filter. Other compensating filters may be combined with the yellow filter.

It is claimed that the higher blue speed of the top layer permits a certain amount of control over the layers preferentially printed in the three-layer material to the extent of describing the result as "two and a half" colour. (See Technichrome and Cinecolor.)

For the yellow printing filters, Ilford filters 101-110 are employed.

"Chromart Tricolor" Negative-Positive Process

The three-colour negative-positive process announced by the company as shortly to become available has the following characteristics. The negative is a tripack of unconventional design of which the top layer can be stripped. This layer is blue sensitive and contains *no* colour coupler.



Blue sensitive — No coupler
Stripping plastic interlayer dyed yellow
Red sensitized — Extra red Magenta coupler
Ortho sensitized — Cyan coupler
Film Base
Anti-halo backing

The positive material to be mated with this negative has the following construction:

Red sensitized — Magenta coupler
Ortho sensitized — Cyan coupler
Colloidal Yellow Filter
Blue sensitive — Yellow coupler

Negative Processing Procedure

The blue sensitive stripping layer is developed, fixed, washed and dried without the solutions having penetrated to the layers lying below the plastic interlayer which is presumed to be impermeable. It is possible to make a positive duplicate print from the silver image now present in the top layer only by means of infra-red light, a positive stock sensitive to infra-red naturally being used. After this "lavender" has been made this top layer negative can be dispensed with by stripping and scrapping it. The original film carrier now bears the second and third layers only and these are colour developed as a two-layer material to magenta and cyan respectively.

We have now achieved the following:

We are in possession of a black-and-white positive duplicate representing the blue separation, and an original two-layer colour negative representing the green and red separation. It is the intention of the inventor that these two films shall comprise the original "master negatives." The next stage is to proceed to make a first generation black-and-white duplicate negative from the "lavender," and then proceed to duplicate the two-layer colour negative upon a special positive duping material.

Colour Positive Master Duplicating Material

Structure:

<i>Sensitizing</i>	<i>Coupler Incorporated</i>
Red sensitized (No green sensitization)	Extra red Magenta
Ortho	Cyan

A print is made on this material which yields an intermediate colour positive. From this colour positive a new duplicate colour negative is made on a material of similar structure to the positive master dupe but having the required contrast characteristics to yield a satisfactory colour negative.

Release Colour Positive

This film is a three-layer material having the following unorthodox structure.

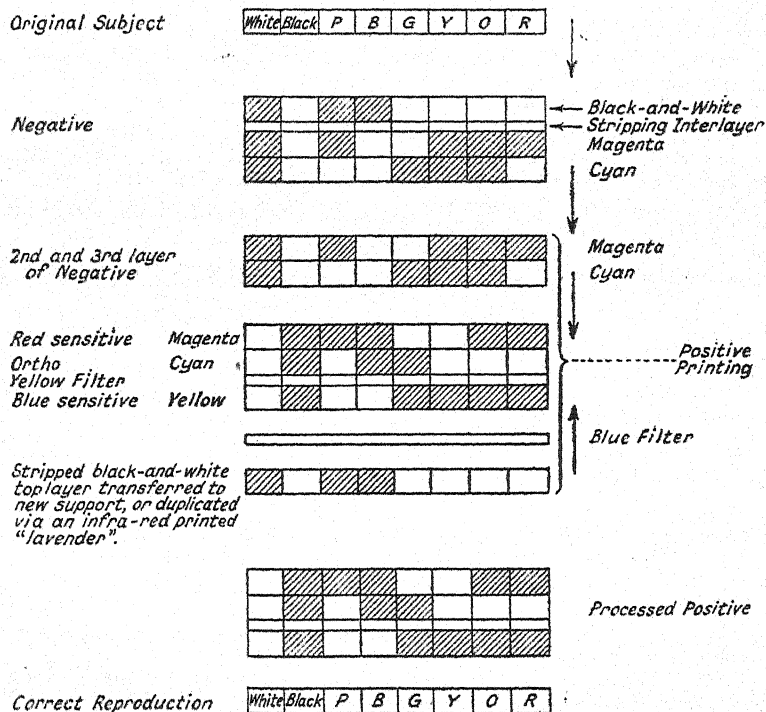
The top layer is red sensitive, without green sensitizing, and contains a magenta colour coupler; the middle layer is ortho sensitized and contains a cyan colour coupler. Next in order comes the usual colloidal silver yellow filter, and the bottom layer is blue sensitive only and contains a yellow colour coupler.

Structure:

<i>Sensitizing</i>	<i>Coupler Incorporated</i>	<i>Filter Layer</i>
Red sensitized (No green sensitization)	Magenta coupler	
Ortho	Cyan coupler	
—		Colloidal silver yellow filter
Blue sensitive only	Yellow coupler	
	Film Base	

The duplicate two-layer colour negative is used to print the upper two layers and the black-and-white duplicate negative is printed upon the opposite side of the stock through the film base, a blue filter being employed to restrict the printing light strictly to the blue region of the spectrum.

Eliminating the duplication stages, the synthesis and analysis would turn out to be as follows:—



Processing

DEVELOPMENT TIME-TABLE
CHROMART "SIMPLEX" NEGATIVE AND POSITIVE

Step	Description	Time (Mins.)	Total Time (Mins.)
1	Development	10	10
2	Rinse	1	11
3	Acid Stop Bath	1	12
4	Washing	30	42
5	Bleaching Bath	7	49
6	Washing	7	56
7	Fixing	8	64
8	Washing	10	74
9	Dye fixation	6	80
10	Final Wash	7	87

COLOUR CINEMATOGRAPHY

Processing of the proposed negative and positive Chromart "Tricolor" negative material will be similar to the "Simplex" two-colour negative and positive. The inventor claims that duplicate colour negatives can be made of superior quality to other colour negative-positive processes, but no evidence in support of this claim has been presented to the industry at the date of writing.

Remarks

It is impossible at present to comment upon the advantages or disadvantages of these unusual multilayer films since at the time of writing too little work has been demonstrated to enable any reliable conclusion to be drawn. There would seem to be no reason why the "Simplex" process should not be capable of acceptable two-colour prints, but it is doubtful whether the claim of the sponsors of this process that "the process produces considerably better results than any of the bipack processes now in commercial use" can, in fact, be upheld.

ALFACOLOUR

(Alfa Photographic Laboratories, Ltd.,
72, Wardour Street, London, W.1.)

Classification.—Two-colour process.

Camera.—Normal, equipped with suitable pressure plate and bipack magazine.

Negative Film Stock.—Gevaert Bipack Film is used.

Printing.—"Duplitized" positive made by Gevaert, namely, coated on front and rear of film support. Obviously, registering pin step-by-step printing machines must be employed.

Processing.—By surface colour development. The orange-red colour development is carried out by a successive use of magenta and yellow colour developers. The sound track is printed on the cyan side. This track is claimed to give normal results with the standard phototubes. This must mean that the cyan dye is an efficient red absorber. The definition is good and the volume level is said to be only slightly lower than that given by a silver track.

Remarks

Direct colour development as a procedure has not so far given reliable results for motion picture processing, and it remains to be seen whether the Alfa technicians have anything really new to offer. A small laboratory is in course of erection at Redhill, Surrey, England.

The company forecasts the early production of a negative-positive multilayer three-colour process. This, however, would involve the provision of very extensive emulsion coating plant not at present at the disposal of this company. The material would presumably conform to the published specifications of Agfacolor negative and positive film.

APPENDIX 13

RECENT LIGHTING EQUIPMENT

G.E.C. Compact Source Illuminators

130/140 amp. (10 kW.) Experimental "Compact" Source Spotlight. This unit comprises a 150-amp. H.I. Arc Lamp body, but the internal mechanism is specially designed to accommodate the 10 kW. Compact Source Lamp. The 10 kW. lamp is mounted vertically with a 20-in. diameter Fresnel lens in front and a spherical backing mirror behind the lamp. "Simmering" mechanism is provided. Full electrical and mechanical interlocks are provided to ensure safety to the lamp and to the operator. The ballast resistance with this unit is separate from the spotlight, but the starting mechanism is an integral part of the lamp house.

Two types of starting mechanism are available, one of the type where the lamp must be allowed to cool down before it can be re-started, the other, of the hot re-start type, where the lamp can be re-started immediately.

35 amp. ($2\frac{1}{2}$ kW.) "Compact" Source Studio Spotlight. This spotlight is a completely self-contained unit in that the ballast and control mechanism forms an integral part of the lamp house, and a twin core cable fitted with a spider plug comes from the control panel. The $2\frac{1}{2}$ kW. lamp is mounted vertically with a 10 in. diameter Fresnel lens in front of the lamp and a spherical backing mirror behind it. Full simmering is provided. Here again, full electrical and mechanical interlocks are provided to ensure safety.

35 amp. ($2\frac{1}{2}$ kW.) "Compact" Source Studio Floods, remote control type. These units use the same lamp as the 35 amp. ($2\frac{1}{2}$ kW.) Compact Source Studio Spotlight. Optically they are in every way similar to the manually operated types. With the remote control up to six units can be inter-connected from one hand controller, and lamp striking and shutter operation—i.e., simmering and full light output—are controlled from the one controller. The number which can be remotely controlled is not limited to 6; as many as are required for a particular set can be connected in banks of 6 and remotely controlled.

"Compact" Source Hand Torch. For burglary scenes and the like. The torch is of approximately the same size as an ordinary torch, but accommodates a 125-watt Osram Compact Source Lamp. Its control mechanism provides for automatic simmering when the torch is placed on the rest.

M-R Type 450 Arc ("The Brute")

The American Mole-Richardson lamp, nicknamed "The Brute," is distinguished by an exceedingly high efficiency; as compared with the Type 170 lamp, an increase of 50% in current—from 150 to 225 amps.—increases the light output three or four times.

A feature of the British model is that access to the mechanism is secured not through doors in the lamp-house, but by pivoting the whole of the mechanism towards the rear. An indication is provided showing when the positive carbon is nearing the end of its run, by the flashing of a pilot lamp, which serves also as a polarity indicator. The lamp is fitted with a 24 in. Fresnel lens.

Maintenance is facilitated by the easy removal of the mechanism from the lamp-house. The burning hours of a lamp are indicated on a counter.

Remote Control System for Studio Lighting

Mole-Richardson (England), Ltd., have demonstrated a system for dimming a number of lights simultaneously by remote control consisting of shutters of the

Venetian-blind type, mounted on each lamp, provided with a motor drive. The system of operation resembles the Selsyn system, but operates on the D.C. of the arc supply.

The control unit consists of a tapped resistor; tappings are connected to appropriate poles in the six-pole stator of a small motor, within which a two-pole armature rotates, its movement exactly following the movement of the control contacts.

A single hand control will operate six shutters, which may, of course, be on lamps of different types, or for example with differently coloured filters; further, a reversing switch on each shutter motor enables it to be either opened or closed on the movement of the controller, so that a gradual change of colour may be effected.

By means of a motor-driven controller, up to 200 lamps can be controlled in gangs of 50. Furthermore, the shutters can be made to close instantaneously, and may be operated by a practical switch on the set.

A unit has been constructed consisting of a spot rail fitted with five studio lamps, comprising two M-R Type 170 arcs operating in series and fitted with automatic striking, one "Duarc," and two M-R Type 414 Senior Solarspot-lamps. All are controlled by means of contactors operated from a console on the floor, providing remotely operated switching, dimming and colour-changing.

Recent compact source lamps manufactured in England by this company are a spotlight designed to take a 10 or 5 kW. lamp. This is remote controlled and gives more light than the M-R Type 170 at 10 kW. The lamp may be struck, dimmed, focused and simmered from a small controller. Run-up time is only 3 to 4 minutes, and a restriking circuit enables the arc to be re-ignited if it has been switched off. A built-in motor controls focus and another a dimming shutter.

A remote controlled floodlight is designed for 5 to 2.5 kW. lamps, and at the former rating produces twice as much light as a "Duarc."

Multiple H.D. Lighting Equipment

Multiple H. D. Industries, Ltd., provide the following lighting equipment:

1 kW. "Compact" *Source Lamp, in all-weather housing.* This lamp is designed for maximum flood. Between the outside of the reflector and the outer casing, a continuous air circulation is maintained, thus achieving great efficiency in cooling. It is operated by one switch which automatically allows a time lag from the initial striking to the full capacity of the lamps, which varies from 1 to 2½ minutes.

This unit is also made using a 2½ kW. bulb and is adaptable either as a sky-pan or in standard 2 kW. spot housings.

10 kW. *Lamp.* Similar in design and construction to the 5 and 7½ kW. models, these units have three switches at the rear, the simmering, striking, and main. The initial run-up period is approximately 15 minutes. The oven, or pre-heating arrangement, is automatically operated in each case from the main switch. With the exception of the ballast resistance, which is housed in a separate unit, either on the stand or in any convenient position on the floor or gantry, the whole of the electrical and mechanical equipment is housed in the rear of the lamp, a patented feature of all lamps manufactured by this company.

200 W. *Streamline Projector Housing, on light collapsible telescopic stand.* The optical system comprises a 3 in. Chance Fresnel lens in conjunction with a spherical mirror. The whole is extremely light, the total weight, including stand and 25 ft. cable, being only 10 lb. The stand enables the lamp to be adjusted to a height of 10 ft. with perfect safety.

A 100 W. model is also manufactured of similar design and construction, but incorporates a 2 in. plano-convex lens.

TABLE 76.—COLORIMETRIC SPECIFICATIONS OF WRATTEN LIGHT FILTERS. (COMMUNICATION No. 1050,
KODAK RESEARCH LABORATORIES.)

Lamp at 2360° K with Wratten filter No. 78																																			
No.	ICI Illuminant A														ICI Illuminant C																				
	X	Y	Z	x	y	λ	p _s %	X	Y	Z	x	y	λ	p _s %	X	Y	Z	x	y	λ	p _s %	X	Y	Z	x	y	λ	p _s %							
1	9864	8966	3119	4494	4085	585	2	8765	8951	10338	3124	3191	574	1.3	8581	8951	8041	3355	3350	568	0.7	8581	8951	8041	3355	3350	568	0.7	8581	8951	8041	3355	3350	568	0.7
2	9810	8930	2926	4528	4122	582.5	7	8597	8891	9549	3180	3298	571	5.5	8472	8902	7515	3355	3377	573.2	5.4	8472	8902	7515	3355	3377	573.2	5.4	8472	8902	7515	3355	3377	573.2	5.4
2A	9845	8973	2953	4522	4122	582.0	6	8617	8941	9603	3173	3292	569.5	5.3	8516	8953	7603	3397	3371	572.8	5.0	8516	8953	7603	3397	3371	572.8	5.0	8516	8953	7603	3397	3371	572.8	5.0
3	9520	8857	1442	4803	4469	580.1	50	7460	8735	3683	3173	4394	569.2	50.5	7640	8808	3243	3380	4473	570.3	48.6	7640	8808	3243	3380	4473	570.3	48.6	7640	8808	3243	3380	4473	570.3	48.6
3N5	3111	2854	0422	4871	4468	581.1	55	2423	2784	1094	3845	4418	570.6	53.7	2477	2795	0978	3963	4472	571.7	51.0	2477	2795	0978	3963	4472	571.7	51.0	2477	2795	0978	3963	4472	571.7	51.0
4	9192	8750	1113	4824	4592	579.0	60.5	7256	8587	2671	3919	4638	569.9	61.7	7475	8632	2395	4040	4665	571.1	59.3	7475	8632	2395	4040	4665	571.1	59.3	7475	8632	2395	4040	4665	571.1	59.3
5	9265	8451	0377	5121	4671	581.5	86.5	6941	8013	0710	4431	5116	572.4	88.1	7129	8056	0645	4503	5089	573.2	87.3	7129	8056	0645	4503	5089	573.2	87.3	7129	8056	0645	4503	5089	573.2	87.3
5N5	3084	2771	0093	5185	4659	582.2	90	2304	2396	0161	4352	5129	573.4	91.7	2363	2616	0143	4613	5107	574.1	91.3	2363	2616	0143	4613	5107	574.1	91.3	2363	2616	0143	4613	5107	574.1	91.3
6	9490	8808	1574	4776	4432	580.0	45.5	7593	8650	4504	3660	4169	569.9	42.0	7711	8616	3749	3829	4310	571.0	41.6	7711	8616	3749	3829	4310	571.0	41.6	7711	8616	3749	3829	4310	571.0	41.6
7	9277	8539	0823	4977	4581	581.0	70	7074	8252	1968	4090	4772	571.1	69.6	7270	8285	1723	4208	4795	572.2	68.9	7270	8285	1723	4208	4795	572.2	68.9	7270	8285	1723	4208	4795	572.2	68.9
8	9206	8402	0484	5088	4644	581.5	82	6909	7999	0988	4346	5032	572.2	83.6	7116	8048	0800	4433	5013	573.1	82.8	7116	8048	0800	4433	5013	573.1	82.8	7116	8048	0800	4433	5013	573.1	82.8
9	9273	8174	0279	5231	4611	582.9	90	6932	7565	0500	4622	5044	574.7	91.1	7124	7612	0451	4691	5012	574.6	89.6	7124	7612	0451	4691	5012	574.6	89.6	7124	7612	0451	4691	5012	574.6	89.6
11	9580	8681	0515	3808	5432	551.3	49.2	2271	4097	1138	3026	5458	549.6	60.6	2334	4062	1015	3149	5481	550.0	58.2	2334	4062	1015	3149	5481	550.0	58.2	2334	4062	1015	3149	5481	550.0	58.2
12	9231	7923	0101	5350	4592	583.9	96.5	6870	7173	0128	4848	5062	576.4	98.0	7049	7232	0130	4891	5019	577.1	97.5	7049	7232	0130	4891	5019	577.1	97.5	7049	7232	0130	4891	5019	577.1	97.5
13	1789	3014	0477	3388	5708	536.2	44	1680	3487	1079	2690	5583	540.8	55.9	1702	3444	0973	2781	5629	539.9	52.9	1702	3444	0973	2781	5629	539.9	52.9	1702	3444	0973	2781	5629	539.9	52.9
15	9066	7447	0059	5471	4494	585.6	98.3	6715	6584	0070	5023	4925	578.7	99.0	6963	6664	0068	5084	4866	579.7	99.0	6963	6664	0068	5084	4866	579.7	99.0	6963	6664	0068	5084	4866	579.7	99.0
16	8884	6836	0030	5641	4340	588.3	99.3	6510	5831	0035	5260	4712	582.2	99.5	6750	5935	0032	5308	4667	582.9	99.5	6750	5935	0032	5308	4667	582.9	99.5	6750	5935	0032	5308	4667	582.9	99.5
17	9519	8942	1106	4865	4570	579.8	61	7315	8799	2699	3905	4702	569.1	63.0	7543	8824	2345	3950	4622	576.0	58.4	7543	8824	2345	3950	4622	576.0	58.4	7543	8824	2345	3950	4622	576.0	58.4
19	8673	6318	0018	5779	4209	590.6	99.6	6268	5211	0020	5450	4532	589.1	99.6	6530	5350	0020	5487	4496	585.7	99.5	6530	5350	0020	5487	4496	585.7	99.5	6530	5350	0020	5487	4496	585.7	99.5
21	8393	5692	0009	5955	4039	593.8	100.0	5969	4503	0010	5694	4296	589.1	99.8	6240	4600	0009	5719	4272	589.4	99.8	6240	4600	0009	5719	4272	589.4	99.8	6240	4600	0009	5719	4272	589.4	99.8
22	7662	4653	0006	6219	3776	599.0	100.0	5265	3441	0004	6045	3950	595.4	99.9	5520	3619	0004	6037	3958	595.2	99.9	5520	3619	0004	6037	3958	595.2	99.9	5520	3619	0004	6037	3958	595.2	99.9
23	6232	3266	0004	6659	3438	607.1	100.0	4041	2209	0003	6463	3533	604.6	100.0	4267	2379	0003	6418	3578	603.4	100.0	4267	2379	0003	6418	3578	603.4	100.0	4267	2379	0003	6418	3578	603.4	100.0
23A	6042	3845	0003	6643	3362	603.9	100.0	4588	2678	0004	6311	3684	600.8	100.0	4870	2871	0004	6288	3707	600.4	100.0	4870	2871	0004	6288	3707	600.4	100.0	4870	2871	0004	6288	3707	600.4	100.0
23B	4822	2461	0003	6619	3378	608.9	100.0	3088	1642	0001	6526	3471	606.2	100.0	3278	1774	0002	6485	3511	605.0	100.0	3278	1774	0002	6485	3511	605.0	100.0	3278	1774	0002	6485	3511	605.0	100.0
24	5253	2513	0003	6762	3235	613.6	100.0	3206	1602	0001	6666	3332	610.4	100.0	3412	1737	0002	6624	3372	609.0	100.0	3412	1737	0002	6624	3372	609.0	100.0	3412	1737	0002	6624	3372	609.0	100.0
24A	5827	2902	0002	6673	3325	610.5	100.0	3698	1909	0002	6593	3404	608.1	100.0	3948	2089	0002	6538	3459	606.5	100.0	3948	2089	0002	6538	3459	606.5	100.0	3948	2089	0002	6538	3459	606.5	100.0
25	4980	2295	0002	6843	3154	616.8	100.0	3038	1425	0001	6805	3193	615.3	100.0	3205	1556	0001	6730	3268	612.5	100.0	3205	1556	0001	6730	3268	612.5	100.0	3205	1556	0001	6730	3268	612.5	100.0
26	4313	1897	0001	6944	3055	621.5	100.0	2564	1136	0000	6929	3070	620.1	100.0	2615	1195	0001	6861	3137	617.5	100.0	2615	1195	0001	6861	3137	617.5	100.0	2615	1195	0001	6861	3137	617.5	100.0
27	3586	2602	0002	6742	3256	612.9	100.0	3337	1673	0000	6659	3339	610.2	100.0	3523	1804	0001	6611	3386	608.6	100.0	3523	1804	0001	6611	3386	608.6	100.0	3523	1804	0001	6611	3386	608.6	100.0
27A	3530	3024	0003	6621	3376	608.9	100.0	3789	2021	0002	6519	3477	605.9	100.0	3980	2156	0002	6483	3513	605.0	100.0	3980	2156	0002	6483	3513	605.0	100.0	3980	2156	0002	6483	3513	605.0	100.0
28	5278	2566	0002	6727	3271	612.4	100.0	3264	1655	0001	6635	3363	609.4	100.0	3465	1773	0002	6613	3384	608.6	100.0	3465	1773	0002	6613	3384	608.6	100.0	3465	1773	0002	6613	3384	608.6	100.0
29	2664	1066	0002	7141	2858	635.2	100.0	1484	0608	0000	7093	2906	631.0	100.0	1438	0589	0000	7094	2906	631.0	100.0	1438	0589	0000	7094	2906	631.0	100.0	1438	0589	0000	7094	2906	631.0	100.0
30	7395	4123	0046	5933	3308	504.4c	52.0	5504	2967	3646	4542	2449	496.9c	55.8	5620	3191	2652	4902	2784	498.0c	52.8	5620	3191	2652	4902	2784	498.0c	52.8	5620	3191	2652	4902	2784	498.0c	52.8

TABLE 76.—COLORIMETRIC SPECIFICATIONS OF WRATTEN LIGHT FILTERS. (Continued)

Lamp at 2360° K. with Wratten filter No. 78																
No.	ICI Illuminant C										Lamp at 2360° K. with Wratten filter No. 78					
	X	Y	Z	x	y	λ	ρ _v	X	Y	Z	x	y	λ	ρ _v	X	Y
30A	+6083	-3181	-0050	-6531	-3415	608.5	96	-3935	-2150	-0205	-6256	-3418	607.0	91.3	-4173	-2319
31	-4488	-1899	-0948	-6119	-2589	512.8c	81.5	-3254	-1242	-3545	-4047	-1545	514.7c	88.8	-3082	-1249
32	-4274	-1819	-1833	-5392	-2295	549.8c	80.0	-3525	-1355	-6593	-3072	-1181	552.0c	79.3	-3221	-1299
32A	+5396	-2810	-2547	-5018	-2613	538.3c	82.1	-4563	-2457	-8759	-2892	-1557	557.2c	88.8	-4325	-2473
33	-2543	-1007	-0213	-6758	-2676	506.2c	89.2	-1542	-0382	-0794	-2894	-1994	497.5c	88.8	-1438	-0359
34	-0430	-0109	-1058	-2693	-0683	577.7c	93.3	-0923	-0122	-4229	-1750	-0232	595.0	95.0	-0711	-0118
34A	-1249	-0435	-1187	-4350	-1515	571.5c	90.8	-1421	-0267	-4671	-2235	-0420	563.7c	94.3	-1180	-0290
35	-0340	-0101	-0420	-3949	-1173	573.7c	96.3	-0476	-0067	-1790	-2040	-0287	565.2c	96.0	-0384	-0073
36	-0090	-0026	-0128	-3690	-1066	574.8c	96.2	-0141	-0014	-0566	-1956	-0194	565.7c	98.2	-0122	-0023
38	-2663	-3549	-2607	-3020	-4024	494.1	34.7	-3469	-4223	-8782	-2106	-2563	483.2	41.5	-3173	-4160
38A	-0652	-1142	-1914	-1758	-3080	488.4	68.9	-1516	-1630	-6583	-1558	-1675	478.1	72.9	-1252	-1574
39	-0220	-0041	-1087	-1631	-0304	452.0	97.0	-0835	-0106	-4316	-1588	-0202	450	99	-0580	-0090
40	-1086	-2860	-0799	-2289	-6027	512.5	51.6	-1272	-3626	-1860	-1882	-5366	514.7	44.6	-1220	-3522
40A	-1349	-2858	-05084	-2939	-6227	531.9	55.0	-1390	-3409	-0795	-2486	-6094	538.1	65.4	-1386	-3340
42	-0706	-1327	-2236	-1654	-3108	488.8	71.0	-1700	-1907	-7740	-1498	-1681	478.7	75.2	-1378	-1837
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45	-0133	-0289	-0882	-1020	-2216	485.2	91.1	-0406	-0559	-2663	-1119	-1541	480.3	90.0	-0344	-0517
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46	-0115	-0101	-0748	-1193	-1048	475.9	96.2	-0400	-0231	-2443	-1302	-0751	471.1	95.2	-0325	-0212
47	-0222	-0102	-1303	-1364	-0627	468.9	97.0	-0862	-0240	-4730	-1477	-0412	461.3	96.8	-0645	-0216
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48	-0133	-0082	-0835	-1267	-0781	472.4	97.3	-0472	-0203	-2788	-1363	-0586	467.8	96.3	-0386	-0190
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"The returning sun exhaled Earth's humid bubbles, and emulous of light reflected her lost forms, each in prismatic guise."—*Fallacies of Hope* (J. M. W. TURNER).



THE END.